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DOCTORAL THESIS

Stand up paddle boarding: an analysis of a new sport and recreational activity

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**BOND
UNIVERSITY**
FACULTY OF HEALTH SCIENCES
& MEDICINE

STAND UP PADDLE BOARDING: AN ANALYSIS OF A NEW SPORT AND RECREATIONAL ACTIVITY.

Ben Schram

Submitted August 2015

A thesis submitted in total fulfilment of the requirements of the degree of Doctor of Philosophy
(PhD)

Faculty of Health Science and Medicine

Abstract

Stand up paddle boarding (SUP) has been described as the fastest growing sport in the world. In theory SUP possesses many facets of an ideal rehabilitative exercise. These include being performed in standing, utilising multiple muscles for stability and propulsion and performed in both dynamic and unstable environments. Advocates have reported SUPs benefits to fitness, core strength and balance, yet a review of the literature, at the time this thesis was written, found only two papers on its reported benefits. Both of these papers were found to be of poor methodological quality leaving a void in scientific research published on the sport or on SUP's proposed benefits (Chapter 2). Consequently there is little validated information in the research literature regarding training and competition preparation and the acute and chronic effects of SUPs participation.

Due to the aforementioned lack of information, Chapter 3 aimed to explore the sport of SUP. An initial performance analysis was undertaken on an elite SUP competitive race to determine and identify key elements and attributes important to SUP. Paper 1 highlighted the importance of physiological parameters which included both aerobic and anaerobic fitness. Participants were shown to spend a majority of a race both within 80-100% of their age predicted maximal heart rate and also requiring themselves to match the speed of waves to maximise propulsion. Additionally, the importance of musculoskeletal parameters including muscular strength and endurance were highlighted by the necessity to be paddling for in excess of an hour. A high level of balance control was also found to be important due to the dynamic environment in which it is performed. Race performance analysis found only a moderate correlation ($r=0.38$) between distance covered and position over the line. This finding suggests that both technical and tactical factors also influence race results along with extrinsic and intrinsic variables such as swell (direction and height), water currents, wind, race line chosen by the competitor, power output of each stroke and length of stroke.

Chapter 4 explores the methodological design required to assess SUP. Paper 2 directly compares the maximal aerobic power of elite SUP athletes in tightly controlled conditions of a laboratory to field based measures. The results of this study found that laboratory based measures demonstrated a high correlation ($r=0.907$) to field based measures. Despite minimal research existing on the sport of SUP, comparisons were made to other similar water based sports that included canoeing, kayaking, surfing and dragon boat racing. Elite SUP athletes were found to

possess aerobic power similar to elite athletes from these listed sports of which were upper limb dominant water based sports. A pilot (Pilot Study 1) then assessed the activity of relevant muscles while stand up paddle boarding. The results of this pilot found a number of methodological challenges which included signal drop out, water protection of EMG, difficulty in establishing a true MVC and also inconsistent results due to variations in paddling technique. Alternative methods of quantifying muscle activity were then explored resulting in the utilisation of isometric endurance testing for the research to follow. Finally, ways of inferring dynamic balance ability in sport was explored for use in SUP to complete the methodological design/exploration.

Chapter 5 profiled individuals across a range of paddling SUP abilities. Paper 3 directly compared three groups which included elite SUP, recreational SUP and sedentary individuals. The results published in this publication found a significantly greater aerobic and anaerobic fitness in elite SUP when compared to both recreational SUP and sedentary controls. Trunk muscle endurance was found to be significantly higher in the elite group when compared to the recreational and control groups. Further, static and dynamic balance displayed significantly greater balance ability in the elite group when compared to both the recreational and sedentary control groups. The results of this study provided normative values for elite SUP and also showed that the sport of SUP is associated with high levels of aerobic and anaerobic fitness, trunk muscle endurance and increased levels of balance.

Chapter 6 evaluates the acute and chronic effects of SUP and presents the final paper of this thesis (Paper 4). This consisted of an intervention study in which a group of untrained individuals (n=18) were recruited for a six week training programme utilising stand up paddle boarding as the training tool. Compliance to the training was found to be high with 90.27% attendance by participants during the research. At the end of this study significant improvements in fitness, strength and self-rated quality of life were reported. Long-term follow up after a year further demonstrated improvements in these aforementioned areas and maintenance of the initial gains of the SUP training activity.

In conclusion, the results from this research provide evidence for the anecdotal claims of the benefits for participation in this new aquatic activity of SUP. Stand up paddle boarding is associated with high levels of aerobic and anaerobic fitness, core muscle strength and balance. It is an enjoyable, alternative means of training with a multitude of health and fitness benefits. This

thesis has uncovered novel data in regards to the performance aspects essential for success in SUP from a competitive aspect and also provides evidence for the positive health and fitness benefits associated with its participation.

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Keywords

SUP, Stand Up Paddle Boarding, Stand Up Paddle Surfing, Paddle Boarding, Profiling, Intervention.

Australian and New Zealand Standard Research Classifications (ANZSRC)

110317 - Physiotherapy.

Author's Confirmatory Statements

The opinions expressed in this study are those of the author and do not necessarily reflect those of Bond University.

The National Statement of Ethical Conduct in Human Research (developed jointly by the National Health and Medical Research Council, Australian Research Council and the Australian Vice Chancellors Committee, March 2007) has been strictly adhered to during the conduct of this research.

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List of Abbreviations

AIHW – Australian Institute of Health and Welfare

ANOVA – Analysis of Variance

AP – Anterior to Posterior

AuSUP – Australian SUP

BF – Biceps Femoris

BMI – Body Mass Index

BOSU – Both Sides Up

COP – Centre of Pressure

EMG – Electromyography

EC – Eyes Closed

EO – Eyes Open

Eo – External Oblique

ES – Erector Spinae

Gmax – Gluteus Maximus

Gmed – Gluteus Medius

ISA – International Surfing Association

JMSUP – Jamie Mitchell Stand Up Paddle Company

LDL – Low Density Lipoprotein

HDL – High Density Lipoprotein

HR – Heart Rate

HRmax – Max Heart Rate

MF - Multifidus

ML – Medial to Lateral

MVC – Maximal Voluntary Contraction

PL – Peroneal Longus

RA – Rectus Abdominus

sEMG – Surface Electromyography

SENIAM - Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles

SPSS – Statistical Package for the Social Sciences

SUP – Stand Up Paddle Boarding

SUPSA – Stand Up Paddle Surfing Australia

TC – Total Cholesterol

Tri – Triglycerides

QL – Quadratus Lumborum

QoL – Quality of Life

VL – Vastus Lateralis

VMO – Vastus Medialis Oblique

$\dot{V}O_{2max}$ – Maximal Oxygen Consumption

$\dot{V}O_{2peak}$ – Peak Oxygen Consumption

WHO – World Health Organisation

100% square – A square drawn encompassing all data points

Declaration by Author

This thesis is submitted to Bond University in fulfilment of the requirements of the degree of Doctor of Philosophy. This thesis represents my own original work towards this research degree and contains no material which has been previously submitted for a degree or diploma at this University or any other institution, except where due acknowledgement is made.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, data analysis, significant technical procedures, professional editorial advice, and any other original work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my research higher degree candidature and does not include material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or institution of higher learning.

Ben Schram

PhD Candidate

Declaration of Co-Authored Works

The authors listed below have all approved inclusion and publication of the manuscripts contained within this thesis. Relative contributions are provided for each study.

Manuscript	Contribution
Schram, B., Hing, W., Climstein, M. (2015) A performance analysis of a Stand Up Paddle Board marathon race. Under review in the <i>International Journal of Aquatic Research and Education</i> .	BS – 90%, WH – 5%, MC – 5%.
Schram, B., Hing, W., Climstein, M. (2015) Laboratory and field based assessment of maximal aerobic power of elite SUP athletes. <i>International Journal of Sports Physiology and Performance</i> . April 7 [Epub ahead of print].	BS – 90%, WH – 5%, MC – 5%.
Schram, B., Hing, W., Climstein, M. (2015) Profiling the sport of Stand Up Paddle Boarding. <i>Journal of Sports Sciences</i> . [Epub ahead of print].	BS – 90%, WH – 5%, MC – 5%.
Schram, B., Hing, W., Climstein, M. (2015) The effects of Stand Up Paddle Boarding. Under review in the <i>International Journal of Aquatic Research and Education</i> .	BS – 90%, WH – 5%, MC – 5%.



Figure 1: A paddler demonstrating SUP stance and paddle position.

Chapter 1

Introduction

Stand Up Paddle Boarding (SUP) is a relatively new sport and recreational activity which is increasing in popularity around the world due to its proposed fitness and core strength benefits (Hammer, 2011). It is widely described online as the fastest growing aquatic sport in the world (Stand Up Paddle Industry Association, 2014). An example of its increasing popularity is that there is no mention of SUP Surfing in Matt Warshaw's definitive Encyclopaedia of Surfing from 2003 (Warshaw, 2003) and yet google search results today yield an excess of 2 200 000 hits.

According to recent studies on the surf industry, SUP had sales in 2008 in excess of 7.2 billion dollars with some being convinced it will soon be an Olympic sport (Helliker, 2010). Stand up paddle boarding is a hybrid of surfing and paddling in which people can either distance paddle or surf waves (Walker, Nichols, & Forman, 2010). Many websites anecdotally advocate the use of SUP to increase strength, fitness, core stability, balance and decrease back pain. However our recent review of the literature found minimal scientific evidence to substantiate the proposed benefits.

1.1 History

Paddle boarding as a sport has its origins in the Hawaiian Islands and is also known by its Hawaiian name Hoe he'e nalu (Argyle, 2011). In the early 1960s post war tourism boom, the Hawaiian beach boys would paddle out on their board using outrigger paddles so that they could take pictures of tourists trying to surf. From this, the alternative name of beach boy surfing developed.

Despite its conception in the 1960's, its relative rebirth was during period of flat swell early in the 2000's in which pro surfers such as Dave Kalama and Laird Hamilton utilised stand up paddle boards as a means of maintaining fitness and their ocean skills (Addison, 2010). From what was initially just utilising a paddle on a larger Malibu surfboard, people began to take notice and become interested. From there the first official SUP contest was held in 2004, at the "Buffalo Big Board Contest" in Hawaii (USA) which received an overwhelming 49 entrants including many past world champion surfers (Pokaku Beachboy Paddles, 2006). The year 2004 also saw the first time that an entrant into the Quiksilver Molokai to Oahu completed the course solo in a time of six hours (Pokaku Beachboy Paddles, 2006).

The inaugural International Surfing Association (ISA) World Stand-up Paddle and Paddleboard Championships were held in 2012 in Peru after recognition from the ISA earlier that year. Affiliation with the ISA is by no means a minor step in the sports growth. The ISA is recognised by the International Olympic Committee as the World Governing Authority for Surfing and includes representation of surfing bodies from 69 countries (International Surfing Association, 2012). International competitions offer financial prizes up to \$20 000 per event (Stand Up World Series, 2012), and despite Australia winning the inaugural team championship title, limited scientific research is available on SUP either locally or internationally.

The year 2012 also marked the 16th annual Molokai-2-Oahu Paddleboard World Championships, one of the most famous SUP distance paddle events. The event currently hosts over 300 total and in excess of 150 SUP entrants each year who attempt to cross the infamous Ka'iwi channel in Hawaii, nicknamed the channel of bones due its reputation of one of the world's most treacherous bodies of water. The channels bad weather and large ocean swells have led to the destruction of entire ancient canoe fleets, modern day fisherman and watermen. This 32 mile (51.48km) ocean race is the ultimate challenge for pro surfers and watermen to test their physiological endurance and wave riding skills amongst up to 12 foot (3.65m) waves and strong currents (Surf Tech, 2012).

Stand up paddle boarding is a sport which is expanding rapidly internationally as more and more individuals realise the enjoyment and benefits attainable from this unique aquatic activity. Locally, from what was originally a group of smaller clubs with individual races, Surfing Australia has now recognised stand up paddle boarding as a Surfing Australia sport. From each state hosting their own SUP titles, the series culminates in the Australian SUP titles to determine who

will represent Australia at the ISA world SUP titles (Surfing Australia, 2012). Divisions included in the Surfing Australia SUP Series include surfing, technical racing and marathon racing.

Early in 2013, Australian United Stand Up Paddling (AuSUP) was created and recognised as the national advisory body for SUP by Surfing Australia. It is comprised of state representatives from Surfing Australia affiliated clubs and associations, and aims to provide guidance and support to Surfing Australia and respective state governing bodies, and to be the representative voice of SUP enthusiasts alike.

1.2 An Overview of the Activity

Stand up paddle boarding is a physical activity in which the participant maintains a standing position on a board similar to a surfboard. However, stand up paddle boards are longer in length (8-15', 2.44 - 4.57m), thicker (4-8", 10.16 – 20.32cm) and wider (26-31", 66.04 – 78.74cm) than traditional surfboards. The SUP participant propels the board across the surface of the water by the use of a long, single-bladed paddle (Walker et al., 2010). Over time surfers have begun to take notice of SUP and began experimenting with paddle boards to train and fine tune their skills and to build core strength and balance.

There are two distinct environments in which SUPs are used, the calm water of rivers and lakes and the open ocean. Recreational use of SUPs through rivers is a common sight in many parts of the world, while it's now rare to see a popular surfing break in Hawaii, Australia or the continental United States without someone out on a SUP. Stand up paddle boarding versatility makes it a great option for surfers to maintain their fitness and remain in the water when there is extended periods of small surf.

Stand up paddle boarding involves a participant getting to their feet on a large board before using the long paddle for propulsion with strokes on either side of the body. Paddling involves the similar biomechanics of dragon boat racing which has the paddling mechanics of an entry, drive and exit of the paddle from the water (Ho, Smith, & O'Meara, 2009). The catch is the term which describes when the paddle enters the water. The pull describes when the paddle is submerged and drawn through the water. During the pull phase the force applied through the paddle is greater than the air and water resistance, therefore providing propulsion (Michael, Reid, & Rooney, 2009). Finally the exit or recovery is when the paddle is drawn out of the water in order

to continue the stroke cycle by returning the paddle to the original forward position ready for the subsequent catch.

Paddle boarders hold the paddle's T grip with the hand opposite to the side they're going to paddle on and drive the paddle through the water by extending both the shoulder and torso. After the catch phase, the paddler rotates the trunk and pulls themselves forward past the blade, exiting the paddle at the foot. Exiting the paddle early in a similar manner to dragon boat paddling has been suggested as a way of maximising speed in the water as this has been found to be an ineffective part of the drive phase (Ho et al., 2009). This technique has also been shown to limit the paddler dragging the paddle which decreases overall drag.

The fact that a paddle can quite often become competent paddling around on a SUP within a few hours is a big attraction to the general public and novice participants. Calmer waters are much easier to balance than waters affected by wind or waves. In essence SUP is similar to canoeing, however whilst standing. It requires a rhythmic alternating paddle to propel the craft through the water. Isometric contractions of the entire trunk, gluteals and lower leg musculature are required to counter the rotational forces from the pull phase of each paddling stroke.

The general disciplines of SUP competition include technical racing, marathon racing and surfing. Technical SUP racing consists of a 4-8km sprint in which participants are limited to a maximum board length of 12'6" (3.81m). The SUP marathon race, normally over a distance of 20km (12.43miles), allows boards up to 14' with a fixed fin. Surfing events are held in heats of 20 minutes and 30 minute finals in which the top two scoring waves are counted toward the competitors total (Stand Up Paddle Association, 2012). Scoring is based upon performing manoeuvres, creating power and speed and getting through closing out sections in a similar manner to traditional surfing (Stand Up Paddle Association, 2012).

When surfing a SUP in the ocean, the similarities to traditional surfing intensify. There is a greater view of oncoming waves from the advantageous standing height making catching waves easier. Unless paddling from an inlet or river, the same physically demanding task of paddling through or around the breaking waves is required. If surfing a wave, a rider must turn, adopt a surfing position, and match the speed of the wave in order to catch the forming wave. As SUPs tend to be much bigger than traditional surf boards, they are quite often easier to catch waves than even the larger Malibu surfboards. Due to the fact that catching a wave is so easy, SUP riders can

occasionally be the source of backlash from other wave riders all wanting to have their share of the waves.

Once on a wave, the SUP rider can then choose to perform various manoeuvres along the wall of the wave the same way a surfer would, until the wave breaks. A combination of balance, flexibility, strength, endurance and reflexes are all required to adapt to a dynamic environment while the wave is breaking. As with surfing, the environmental conditions such as swell size, wind direction, tides and currents all play a role in the SUP surfing session.

Distance and down-wind paddle races are also popular in the open ocean. The advantage of this is that courses can be altered depending on the wind to ensure coasting on wind generated swells. Distances in excess of 300km have been performed over a number of days in the open ocean, while the marathon race 'Molokai in Hawaii' is over a 32 mile (51.5km) open ocean course.

Although clearly increasing in popularity and enjoyable, minimal scientific research on its benefits exists. In theory, there are aspects of SUP which could be beneficial. The rationale for SUP to be of benefit will be addressed in the next section.

1.3 The Potential for Benefit

Numerous anecdotal reports about SUP benefits exist, primarily revolving around fitness, core strength and balance. Stand up paddle boarding is an activity which has been described as a full body workout. The minimal research conducted thus far demonstrates that most people do not reach their anaerobic threshold when paddling on a SUP. Most subjects researched previously reached 60-80% of their maximum heart rate, a level considered ideal for endurance training (Ruess et al., 2013b)

Theoretically, due to SUP being performed in an unstable environment, it is reasonable to assume that it would be good for improving balance. While the standing position is unstable to begin with, it is continuously disturbed by the motion of the board and paddle in the water and the movement of the arms in the air, providing a constant postural challenge. It demands a high amount of balance with a posture of knees bent, hips forward, back straight and head up, looking at the horizon. This stance is also known as the neutral power stance in yoga (Stanger, 2010). This posture adopted in SUP forces the paddler to utilise postural muscles. It has been previously found that relaxed postures rely on passive lumbopelvic support structures for the maintenance of upright position against gravity (O'Sullivan, 2002). The adoption of these slumped postures has been associated with motor dysfunction of the spine stabilising muscles including the lumbar multifidus and the deep abdominal musculature (O'Sullivan, 2000).

Due to SUP exercise being performed whilst standing, the trunk muscles are required to contract to provide a stable base for the paddling motion to occur. The fact that these key trunk muscles are required to be active could be adequate strengthening for the core musculature with chronic participation. In a similar manner to the potential fitness benefits, it may be ideal at building core muscle endurance, something which is often lacking from people who suffer from back pain (Schellenberg, Lang, Chan, & Burnham, 2007).

It has been shown that multi-muscle therapeutic exercise is more effective than isolated transverse and multifidus training for strengthening the peri-spinal musculature (Koumantakis, Watson, & Oldham, 2005) and that performing exercise in a neutral spinal position leads to better outcomes (Sun et al., 2006). Both of these points demonstrate that standing, functional exercises, performed in a neutral spine position, recruiting multiple muscles, could potentially be

excellent rehabilitative exercises for those people whose back pain is attributed to instability or loss of control around spinal segments.

Stand up paddle boarding activity may be less strenuous on the body than other water based sports. Stand up paddle boarding is low impact; therefore has no repetitive impact on the joints, making it suitable for mature aged individuals suffering from arthritic degenerative changes through the lower limb. Walker's study in 2010 reported that some participants of paddle boarding also rode long boards, short boards and paddled outrider canoes (Walker et al., 2010). Despite sharing many similarities with surfing, SUP is a quite distinct, unique sport. Unlike surfing the pop-up phase from a hyperextended position does not exist as the athlete is already standing, decreasing stresses on the low back. A recently conducted survey demonstrated that the low back and neck were the most common chronic injuries associated with surfing (Furness et al., 2014).

The use of a SUP could be ideal early after injury. It has been suggested that in the early stage of musculoskeletal injury, while force and power can be decreased due to the effects of inflammation, pain and stiffness, an unstable surface training program might be an ideal initial exercise to prevent the loss of force and power often associated with injury (Behm & Colado, 2012). Post ankle injury, studies have demonstrated the improvement in postural sway and decrease in recurrence from balance training (Hupperets, Verhagen, & van Mechelen, 2009; Kidgell, Horvath, Jackson, & Seymour, 2007).

As with canoeing and kayaking, propulsion of the craft relies upon muscle actions of the upper body while it shares the bilateral paddling motion associated with kayaking, preventing any muscle imbalances associated with unilateral paddling. The fact that it is performed while standing, decreases the shearing forces on the spine associated with rotational movements encountered in kayaking (Bono, 2004). Poor technique however, may involve lumbar flexion and rotation or adopting impingement positions of the shoulder, providing further rationale for scientific investigation.

Another potential benefit of paddle boarding is that it is conducted in bare feet. The intrinsic foot musculature has been found to make a significant contribution to maintaining a stable base of support during dynamic activity (Rothermel, 2004). Bare foot training has been used previously with the assumption that it improves the overall muscle system and trains both the intrinsic and

extrinsic foot muscles (Squadrone, 2009). Anecdotal claims are that the intrinsic foot muscles are highly active during the activity in an attempt to gain grip and stability. Being bare foot on a paddle board is beneficial as high levels of proprioceptive input are relayed to the brain due to the foot having high mechanoreceptor density (Janda, 1996).

Bare foot training is thought to be of benefit as afferent inputs from the sole of the foot can affect postural awareness, (Kavounoudias, Roll, & Roll, 2001) and movement discrimination in the ankle has been found to be much better bare foot when compared to wearing shoes (Waddington, 2003). It has been reported that simply one hour of barefoot activity per day lead to increased arch height and muscle tone (Robbins & Hanna, 1987). Fatigue of the intrinsic foot muscles is reported to increase navicular drop from the lack of control of pronation (Headlee, Leonard, Hart, Ingersoll, & Hertel, 2008). As the stability of the navicular forms part of the longitudinal arch, this may lead to a gamete of overuse injuries such as tarsal tunnel syndrome, metatarsalalgia, plantar fasciitis and medial tibial stress syndrome.

To further understand this sport and recreational activity, it must first be broken down to its basics. While limited research is beginning to emerge on the growing sport of surfing (Farley, Harris, & Kilding, 2011) SUP still is a sport of many unknowns. With the growth of surfing as a sport there has been an associated increase in interest to the physical preparation of the surfing athlete (Farley et al., 2011). With any new sport, there exists a requirement to study and understand what is required to succeed. The purpose of analysing a sport through technical and tactical evaluation and analysis of movement is for development of databases and education for both coaches and participants (M. Hughes, 2004). Utilising a scientific approach to performance analysis of this developing sport, can lead to sporting success for athletes of this sport.

With stand up paddle boarding growing as surfing did many years ago, an investigation into this sport is beckoning to be performed. A major problem facing the investigation of this new sport is that new outcome measures need to be conceived and tested in order to test these athletes. Due to the minimal research this is still a sport of many unknowns. The fitness profile of surfing has been studied in several articles from which comparisons to SUP can be drawn. The aerobic and anaerobic capacity of SUP can be compared to similar water sports such as surfing, canoeing or kayaking. Strength and balance profiles have been investigated both in other sports and also in rehabilitation.

Chapter 2

Literature Review

2.1 Introduction

Advocates for stand up paddle boarding will report a multitude of benefits which arise from its participation. Despite many theoretical benefits, a validation of these benefits through scientific evidence was sought. In order to assess these anecdotal claims, a thorough review of the literature was performed.

2.2 Methods

A literature review was conducted to identify scientific papers reporting evidence of the benefits of SUP. A search of CINAHL (1) SPORTSDISCUS (1) PEDro (0) Embase (1) PubMed (0), along with google scholar was performed (2) in 2013. Inclusion criteria included the articles to be peer reviewed, published in scientific journals, exclusion criteria included if the result was a periodical, or magazine article. Search terms were “SUP”, “STAND UP PADDLE BOARDING”, “STAND UP PADDLE SURFING” and “PADDLE BOARDING”. Since the date of the literature review, research which is presented in this thesis has begun to be published. This research has been excluded for the purpose of this literature review.

Database	Search Terms		
CINAHL	SUP	AND	Stand up paddle boarding
SPORTSDISCUS			Stand up paddle surfing
PEDro			Paddle boarding
Embase			
PubMed			
Google Scholar			

Table 1: Critical review databases and search terms.

2.2.1 Eligibility Criteria

For inclusion in to the review, articles were required to be

- Published in a scientific journal
- Peer reviewed
- In English
- On the proposed benefits of SUP

2.2.2 Exclusion Criteria

Articles were excluded if they were

- Magazine articles
- Periodicals
- Not on the benefits of SUP

2.2.3 Methodological Quality Assessment

In order to assess the methodological quality of the two papers found in the literature on SUP, the Modified Methodological Quality Checklist by Downs and Black was used (Downs & Black, 1998). This methodological quality assessment was completed by both the primary investigator and an independent assessor. The modified Downs and Black checklist utilised for this review is a twenty seven point scale with five subscales examining reporting, external validity, internal validity – bias, internal validity – confounding and power. From these subscales it gives an overall score out of 27 points. Studies are reported to be of poor methodological quality if they score less than 14, fair if they score between 14 and 20 and strong if they score greater than 20. It has been reported that this method of assessing methodological quality has high internal consistency ($r=0.89$), good test-retest ($r=0.88$) and inter-rater reliability ($r=0.75$) (Olivo et al., 2008).

2.3 Results

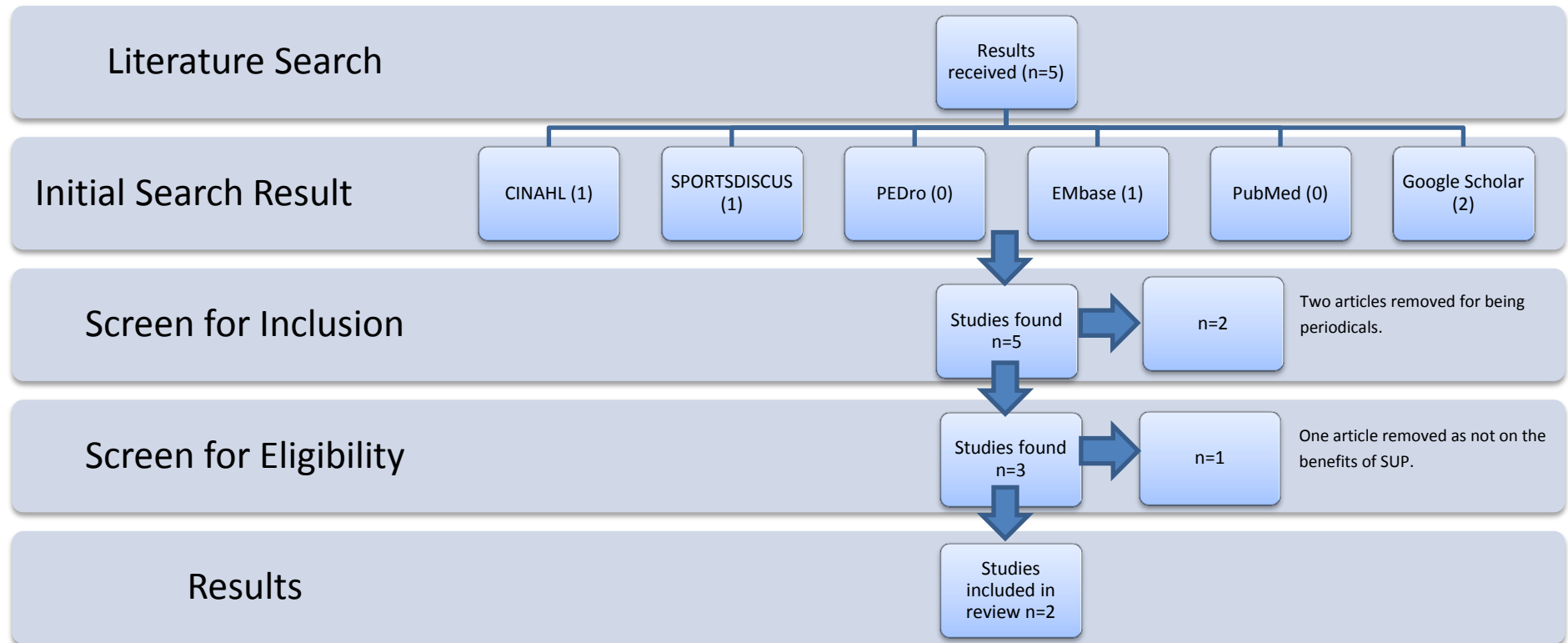


Figure 2: PRISMA flow diagram of the literature review of SUP

2.3.1 Analysing the Results from a Methodological Perspective

In total, only two scientific articles were found on the benefits of SUP, both by the same author (Ruess et al., 2013a, 2013b). The first article examined the physiological and balance effects of SUP, the other examining the activity of trunk and leg muscles during stand up paddle surfing. A general summary of these articles can be found in Table 2. The two papers assessed with the checklist can be found in Table 3. The first paper scored 11 out of a possible 27 for methodological design, while the second scored 13. Both papers were therefore deemed of being poor methodological quality.

The two papers, being from the same authors, were similar in methodological design and therefore had similar strengths and weaknesses. The first paper scored 4/10 for reporting with no inclusion/exclusion criteria being reported, a lack of reporting of adverse events, no actual probability, distributions of groups not clearly described and main findings not being clearly described. The second paper scored 6/10 with respect to reporting with no inclusion/exclusion criteria reported, no reporting on adverse effects, and a lack of actual probability values not being reported. Both papers displayed a high level of external validity scoring 3/3. The external validity questions whether the findings of the study could be generalised to the findings of the population of the subjects recruited for the study.

Likewise, both papers scored a similar score for internal validity – bias. Both papers were scored 3 out of a possible 5 as the subjects were unable to be blinded from the intervention they received, no attempt of blinding of the assessors was made, no indication of length of time was made and minimal appropriate statistical tests were performed. With respect to internal validity – confounding, both papers scored 1 out of a possible 7 due to subjects being different for different parts of the study, subjects not being randomized to intervention groups, intervention assignment was not being concealed and no adjustment for confounding in the analysis made. As there was no power reporting in either study, both were deemed to have scored 0 for power.

Title	Author	Year	Subjects	Methodology	Results	Conclusion
Stand Up Paddle Surfing – An aerobic workout and balance training	Reuss, C., Kristen, K.H., Eckelt, M., Mally, F., Litzenberger, S. and Sabo, A.	2013	68 (44male, 24 female)	Incremental exercise test on an ergometer; measuring HR. Single leg hop test for assessment of balance performance.	HR increased with power output and remained in aerobic zone (Test stopped at 145bpm/25W). Field based: (L) 19.58±10mm to 15.68±9mm in AP direction and 20.28±11mm to 16.12±10mm in ML direction. Minimal change on (R) 19.89±11mm to 19.15±8mm in AP direction and 21.11±12mm to 18.20±7mm in ML direction. Lab based: (L) foot 17.37±8mm to 12.32±7mm in ML direction, 22.3±11mm to 14.02±7mm in AP direction. (R) foot 20.57±6mm to 16.27±7mm in ML direction and 25.67±9mm to 21.17±8mm in the AP direction.	Stand up paddle boarding is ideal for endurance training. Significant improvements in balance can be elicited with 30 minutes of SUP or after an incremental exercise test on an ergometer.

Title	Author	Year	Subjects	Methodology	Results	Conclusion
Activity of trunk and leg muscles during stand up paddle surfing.	Reuss, C., Kristen, K.H., Eckelt, M., Mally, F., Litzenberger, S. and Sabo, A	2013	5 subjects in the lab, 2 subjects in the field.	Wireless EMG analysis of 3 different intensities of paddling. 3 W, 10W and 30W. EMG recordings of Rectus Abdominus, External Obliques, Pectoralis Major, Rectus Femoris, Gluteus Maximus, Multifidus, Erector Spinae, Latissimus Dorsi.	No significant difference between ergo and field EMG, muscles measured showed activation points during various points of the stroke. No discrete numbers reported for % MVC of any muscle. Power phase has the highest duration of stroke, followed by recovery, exit and catch.	All of the studied muscles were active during SUP. The majority of the stroke is from upper body musculature while the trunk, knee and hip stabilisers show high activation.

Table 2: Published articles on the benefits of SUP.

Title	Author	Year	Reporting										External Validity			Internal Validity - bias							Internal Validity - confounding						Power	Total Score	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27		
Stand Up Paddle Surfing – An aerobic workout and balance training	Reuss, C., Kristen, K.H., Eckelt, M., Mally, F., Litzenberger, S. and Sabo, A.	2013	1	1	0	1	0	0	1	0	1	0	1	1	1	0	0	1	0	0	1	1	0	0	0	0	0	1	0		11
Activity of trunk and leg muscles during stand up paddle surfing.	Reuss, C., Kristen, K.H., Eckelt, M., Mally, F., Litzenberger, S. and Sabo, A	2013	1	1	0	1	0	1	1	0	1	0	1	1	1	0	0	1	0	0	1	1	0	0	0	0	0	1	0		13

Table 3: Modified Downs and Black methodological quality assessment of the two SUP papers.

2.4 Discussion

2.4.1 Strengths and Limitations of the Studies

The first paper seen in Table 2 aimed to investigate whether SUP was a suitable endurance and balance training tool (Ruess et al., 2013b). In this study, to its benefit, both field and laboratory assessment were utilised. Laboratory based testing included eight males of various experience while 60 individuals were recruited for the field based assessment. An incremental exercise test was performed on a SUP ergometer beginning at a power output of 6W with an increase of 2W every 2 minutes.

Balance was measured pre and post activity, both in the lab and in the field, utilising a single leg hop test on an electronic baropodometric platform. The subjects were asked to perform five jumps in the lab and two jumps in the field on one leg, and then stand as still as possible for 15 seconds. The subjects were testing on both legs. During the 15 seconds centre of pressure (COP) movement was recorded with respect to both anterior to posterior movement (AP) and medial to lateral movement (ML). It is unclear why subjects were asked to perform single leg balance assessments as SUP is performed in bilateral stance, therefore making the testing criteria non-specific.

The field based participants were asked to paddle at self-selected pace for 30 minutes, meaning that the testing was not standardised for each participant. The participants were split into age groups for analysis of their results. Results from the laboratory based assessment of performance showed that as expected, heart rate increased linearly with power output over time.

Measurement of expired gases was not made, and lactate measurements were not performed. Average subjective termination was at only 145bpm and a power output of 24W, not at maximal pace. Anaerobic threshold was not reached in 62.5% of the subjects. From this finding, the authors claim that SUP is an ideal endurance training modality due to the heart rate intensity being 60-80% of their maximal heart rate.

Results from balance assessment demonstrated that laboratory tests displayed a significant improvement in balance in both AP and ML directions. This finding contradicts other research where previous studies demonstrating that fatigue post activity is usually detrimental to balance control (Nagy et al., 2004). The authors acknowledged that there was however, a high standard

deviation and low number of subjects. The field based assessment of balance showed varying results with some groups showing a decrease in balance. There were high standard deviations and the authors reported improvement in balance amongst the younger groups without mention of significance. With exposure to an activity, improvements can be made. This is known as the leaning phenomenon, where improvement can be evident found in subsequent trials. From this non-significant improvement in the field based assessment, the authors concluded that balance improvements can be seen after a single SUP activity and therefore it is ideal for training balance.

The second article (Ruess et al., 2013a) from the same authors seen in Table 2, investigated the muscle activity of trunk and leg muscles during SUP both in the laboratory on an ergometer and also in the field. Muscle activity and activation were analysed during the four phases of the SUP stroke. Surface electromyography (sEMG) was utilised to analyse the activity of various trunk and lower limb musculature. A total of five subjects performed the stroke on an ergometer, with a further 2 tested on water. Three intensities were utilised at a power output of 3, 10 and 30 Watts.

Results demonstrated that low muscle activity was evident during the catch. Bilateral activation was evident in the gluteal and rectus femoris muscles. Activity of the abdominals (rectus abdominis and external obliques) and the pectorals was found to be active in the power phase while the muscles of the back including the multifidus, erector spinae and latissimus dorsi were primarily active in the exit and recovery phases. Slight differences were reported during lab and field based testing. They demonstrated that similar activation patterns were evident regardless of intensity. Muscles which the investigators deemed difficult to train including the rectus abdominis, external obliques, multifidus and erector spinae were activated especially during the on water trials. These muscles were deemed essential to transmit power between paddle and board through the kinetic chain. From these results, the authors concluded that SUP is ideal for multi-muscle training.

Although the muscles were appropriate and Surface electromyography for the non-invasive assessment of muscles (SENIAM) guidelines were utilised for electrode placement, there were no reports of % of maximal voluntary contraction (MVC) from these muscles, making inferring a training effect difficult at best. Most EMG studies normalise contractions for individuals to infer what intensity that muscle is being recruited to provide an insight into the intensity of muscle contraction, not simply that it is active and when. Due to the reports of muscle activation only,

the claims of SUP being an appropriate tool for training muscles throughout the body, especially the back and abdominals it questionable. Reporting of MVC would at least provide insight into the intensity of contraction and therefore potential for a training effect.

2.5 Conclusion

To date, only 2 papers have been published of poor methodological quality on SUP. There is therefore little information regards the acute and chronic effects of this activity and minimal information is available for participants and coaches alike for training and competitive purposes. Well designed, scientific investigation in to this area is therefore warranted to ensure gaps in the literature are filled and more is known about this sport and activity. To enable investigation into this activity, the attributes important to SUP need to be identified and outcome measures which can be applied to SUP need to be explored.

2.6 Objectives of This Thesis

This thesis investigated stand up paddle boarding, both as a sport and a recreational activity. At the completion of this thesis, the hope is to have a greater understanding of this sport and provide evidence for, or to refute the anecdotal claims of fitness, strength and balance benefits of this activity. Our review of the literature found only two papers regarding the effects of stand up paddle boarding. A thorough critique of these two papers will therefore be performed in Chapter 2.

Due to the lack of scientific research in this area, methodological design is required to ascertain the best way of evaluation of physiological and musculoskeletal attributes associated with this activity. Chapter 3 determines the aspects important to SUP through a performance analysis of a SUP race. As it is a minimally explored area, means of assessment proven in other sports need to be adapted to assess this activity. Some of the assessment techniques utilised in other sports and populations were examined in Chapter 4. The sports deemed similar to SUP include water based sports such as surfing, canoeing, dragon boat racing and surf lifesaving.

The instability associated with SUP is similar to unstable surface training which has increased in popularity due to its proposed strength and balance benefits and therefore has received a reasonable amount of investigation from a scientific perspective. By applying previous validated assessment tools to SUP, information about what it takes to succeed and the effects of participation in SUP will be uncovered through profiling a range of abilities from the SUP population in a profiling study in Chapter 5.

Once an understanding of the various abilities and attributes of participants is discovered, an intervention was performed to determine if a positive health effect of participation is found. This intervention can be found in Chapter 6. An exercise tool if proven to have positive effects on fitness, strength and balance could be then promoted to combat the myriad of issues associated with inactivity such as the obesity epidemic. By providing an enjoyable, alternative method for physical activity with a multitude of benefits, it is hoped that uptake of this activity would have many health and fitness benefits for the general population.

2.7 The Aims of This Thesis

The aims of this thesis are to

- 1) Conduct a literature review and critique the papers in the literature on stand up paddle boarding.**
- 2) Conduct a performance analysis on a competitive SUP event to determine important factors in SUP to guide investigation in this thesis.**
- 3) Do a review on the relative outcome measures utilised in related sports and rehabilitation for use in a stand up paddle boarding population.**
- 4) Profile the sport across a range of abilities in the sport from novice to elite to characterise the sport from a physiological and musculoskeletal perspective.**
- 5) To use stand up paddle boarding as an intervention to assess the benefits of the activity on the previously untrained individual on a variety of health, fitness and wellbeing parameters.**

Figure 3 shows the overview of this thesis with the various papers arising from the research studies. Prior to profiling the SUP population, a performance analysis on a SUP race was conducted to understand more about the requirements of the sport and can be seen in the green box. Due to SUP being an under-researched area, methodological papers to determine the best way of assessing this activity are required and can be seen in the EMG piloting study and the comparison of both lab and field based testing of SUP athletes. The profiling of a broad spectrum of abilities encompasses the sedentary, recreational and elite groups and can be seen within the red box. Finally, the effect of SUP on the previously untrained individual can be seen in regards to the intervention within the blue box.

Stand Up Paddle Boarding	
Chapter 1: Introduction	<ul style="list-style-type: none"> • History of the sport, an overview of the activity and the theoretical potential for benefit
Chapter 2: Literature Review	<ul style="list-style-type: none"> • A thorough search of relevant literature pertaining to the reported benefits of SUP • Two papers identified and reviewed
Chapter 3: Exploring the sport of stand up paddle boarding	<ul style="list-style-type: none"> • Assessing the areas of importance to SUP for investigation via field based analysis of a race • Paper 1 - <i>A performance analysis of a stand up paddle board marathon race</i>
Chapter 4: Methodological design to assess stand up paddle boarders	<ul style="list-style-type: none"> • Physiological investigation of SUP <ul style="list-style-type: none"> • Paper 2 - <i>Laboratory and field based assessment of maximal aerobic power of elite SUP athletes</i> • Introduction to instability training/ assessing muscle activity <ul style="list-style-type: none"> • Pilot Study 1 - <i>An electromyographic analysis of stand up paddle boarding</i> • Assessing balance ability
Chapter 5: Profiling the sport of stand up paddle boarding	<ul style="list-style-type: none"> • Profiling the sport of SUP from a variety of abilities utilising the methods found in chapter 4. <ul style="list-style-type: none"> • Paper 3 - <i>Profiling the sport of stand up paddle boarding</i>
Chapter 6: The acute and chronic effects of stand up paddle boarding	<ul style="list-style-type: none"> • Determining the acute and chronic effects of SUP on the previously untrained individual. <ul style="list-style-type: none"> • Paper 4 - <i>The effects of Stand Up Paddle Boarding</i>
Chapter 7: Discussion, limitations and future research	<ul style="list-style-type: none"> • Summary, suggestions for future research, concluding statement and key features.

Figure 3: Overview of this thesis

2.8 Publications Arising From This Thesis

Papers

1. **Schram, B.**, Hing, W., Climstein, M. (2015) A performance analysis of a Stand Up Paddle Board marathon race. Under review in the *International Journal of Aquatic Research and Education*.
2. **Schram, B.**, Hing, W., Climstein, M. (2016) Laboratory and field based assessment of maximal aerobic power of elite SUP athletes. *International Journal of Sports Physiology and Performance*. (11) 28-32. doi:10.1123/ijsp.2015-0076
3. **Schram, B.**, Hing, W., Climstein, M. (2015) An EMG analysis of Stand Up Paddle Boarding. (Unpublished pilot study).
4. **Schram, B.**, Hing, W., Climstein, M. (2015) Profiling the sport of Stand Up Paddle Boarding. *Journal of Sports Sciences*. Published online 20 Aug 2015. doi:10.1080/02640414.2015.1079331
5. **Schram, B.**, Hing, W., Climstein, M. (2015) The effects of Stand Up Paddle Boarding. Under review in the *International Journal of Aquatic Research and Education*.

Poster Presentations

1. The physiological, musculoskeletal and psychological effects of Stand Up Paddle Boarding Poster Presentation, 2015 World Confederation of Physical Therapists Congress, Singapore. doi:10.1016/j.physio.2015.03.1285

Additional Publications Relevant To This Thesis but Not Forming Part of It:

1. **Schram, B.**, Hing, W., Climstein, M., & Walsh, J. (2014). Profiling Elite Stand Up Paddle Boarders. *Journal of Fitness Research*, 3(1), 40-51.

Chapter 3

Exploring the Sport of Stand Up Paddle Boarding

PREFACE:

Currently little is known about the sport of stand up paddle boarding. In order to understand more about the sport, the next chapter will explore stand up paddle boarding in more depth via a performance analysis of a SUP race. Figure 4 displays the overview of this chapter. Field based performance analyses in sports are explored in section 3.1 while the use of GPS in sport is reviewed in section 3.2. Determining cardiovascular demand in the field is covered in section 3.3 with a review of the literature in performance analysis in other water based sports found in section 3.4. The first study in this thesis is found in this chapter which aims to understand more about SUP as a sport which is found in section 3.5. This study utilises both GPS and HR monitoring to discover more about the physiological demands of this new sport.

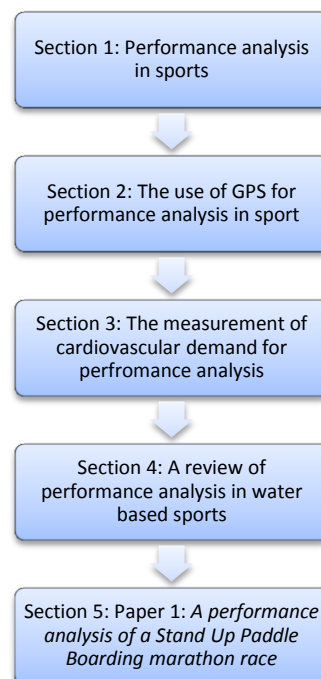


Figure 4: An overview of Chapter 3

3.1 Performance Analysis in Sports

Currently there are no scientific papers on the performance aspect of SUP and consequently little is known about the sport. The assumptions of fitness benefits are completely unsubstantiated. To enable a greater understanding about SUP, a performance analysis of a stand up paddle boarding race was undertaken. Although there are other aspects of SUP including surfing, it is assumed that the principles and requirements will be very similar to the research being conducted in that area.

Performance analysis is the study of parameters or indicators which define aspects of performance aiming to improve future outcomes (M. D. Hughes & Bartlett, 2002). Performance analysis is an essential part of elite sport and encompasses tactical and technical information along with analysis of movement and physical demands (Farley et al., 2011). The ideal measure of an athlete's performance is their competitive standing amongst themselves and in comparison to other competitors. It is thought that there are a number of variables both intrinsic and extrinsic which significantly affect athlete performance during a SUP event. Extrinsic variables include ambient temperature, relative humidity, swell direction and size, currents, wind direction and tides, while intrinsic variables include technique, aerobic and anaerobic fitness and balance. Individual simulated events on dry land such as maximal effort paddles and aerobic tests of fitness using ergometers, strength tests and instrumenting both athlete and equipment are methods used previously by coaches and athletes in order to gain a greater understanding of performance.

3.2 The Use of GPS for Performance Analysis in Sport

Although the majority of physiological testing of athletes is performed under tightly controlled laboratory conditions, these are often not sport specific conditions (Larsson, 2003). The use of global positioning systems (GPS) has recently been identified as a means to monitor physical activity of an athlete, giving such data as position, distance and speed in the field. Global positioning systems can be used in conjunction with other measurements such as portable metabolic gas analysis and telemetry heart rate to enable comparisons to be drawn between the subjects physical activity and physiological response (Larsson, 2003).

Quantifying movement patterns in sport is important for coaches and athletes to be able to develop sport specific conditioning programs. Global positioning system analysis allows more accurate in situ analysis of work rate analysis than traditional video analysis, which has a propensity to erroneously categorise intensities while being laborious to analyse (Cunniffe, Proctor, Baker, & Davies, 2009). Changes in velocity measured by GPS are normally quantified via the doppler shift method. Global positioning system accuracy is determined by both the frequency of the unit and by the number of satellites available and the time of day, as satellites complete a full revolution of the earth in 12 hours (Janssen & Sachlikidis, 2010). A minimum of four satellites are required to obtain a positional reading, with greater accuracy achieved with an increased number of satellites (Larsson, 2003). Time of day has not been found to be an influencing factor for accuracy of positioning in a study performed in Europe (Macleod & Sunderland, 2007) whereas recordings in Australia have been shown to vary significantly with various times of day (Janssen & Sachlikidis, 2010).

Early GPS validation studies in 1997 were made difficult due to the degradation of the accuracy of satellite transmission by the United States Department of Defence. This deliberate hindering was ceased in the year 2000 (Aughey, 2011). Further validation studies were made difficult by the ambiguity of what constituted a gold standard for comparison with the GPS units with some studies using Swiss chronometers (Schutz & Chambaz, 1997), others accelerometers (Terrier, Ladetto, Merminod, & Schutz, 2000) and more recently, trundle wheels to establish a predetermined distance with light gates (Edgecomb & Norton, 2006).

Over time, studies identified that the higher the sampling rate of these units, the more valid GPS becomes for measuring distance and speed (Castellano, Casamichana, Calleja-Gonzalez, San Roman, & Ostojic, 2011). If utilizing 1Hz units, the unit may be incapable of recording athlete movements which take less than 1 second to complete. The more modern 10Hz units have been estimated as having a standard error of the mean (SEM) of 10.9% for a 15m sprint (Castellano et al., 2011). Validity also seems to increase the longer the duration of a task, with standard errors of 3.8% for a 5Hz GPS over 140m, while in 197m activity was just 1.5% (Portas, Harley, Barnes, & Rush, 2010). Higher sampling rates and measures of longer duration have therefore been recommended for greater confidence in recordings (Aughey, 2011).

The reliability of GPS is dependent upon sample rate, velocity, duration of the task and type of task (Aughey, 2011). Johnston demonstrated that the level of 5Hz GPS error increased along with velocity of exercise despite being a valid and reliable measure of total distance covered (% typical error of mean <5%, $p < 0.05$) and peak speed (% typical error of mean 5-10%, $p < 0.05$) (Johnston et al., 2012). Some researchers have had issues with higher speeds and have suggested exercising caution when analysing movement demands > 20km/h (Johnston et al., 2012). Another recent study compared the validity and reliability of 5Hz versus 10Hz GPS units (Varley, Fairweather, & Aughey, 2012). In contrast to other studies, the authors found that GPS accuracy improved at higher constant and starting velocities when compared to lower velocities. They attributed this to less variation in change in velocity. Other findings of this study were that the 10Hz units were two to three times more accurate and six times more reliable than the 5Hz devices for measuring instantaneous velocity. This finding lead the authors to suggest that the more modern units are an acceptable tool for the measurement of constant velocity, acceleration and deceleration and are able to detect changes in performance in team sports (Varley et al., 2012).

In the mid 90's, GPS units weighed approximately 4kg, making athletic competition while wearing the device unviable (Aughey, 2011). This coupled with the fact that in order to be able to worn during competition, the units had to be heat, moisture and impact resistant made sport specific studies difficult to complete. In 2003, GPSports SPI-10 units were made commercially available specifically for sporting applications. These units are ideal for field based testing given that they are heat, moisture and impact resistance and lightweight at only 67 grams. Recently 15Hz GPS units have been developed which will potentially further increase both validity and reliability of these units.

Other sports have utilised these technological developments in the last 10-15 years as GPS units become more reliable and portable. Improvements in technology have seen the availability of GPS systems to coaches and athletes to gain a more in depth understanding of their training and competition habits (Cunniffe et al., 2009). It is not uncommon to see international sports monitored for training load, heart rate and movement patterns in a wide range of sports from Australian Rules Football to horse racing (Kingston, Soppet, Rogers, & Firth, 2006; Wisbey, Montgomery, Pyne, & Rattray, 2010).

Although some sports have encountered difficulty in ensuring an unobstructed view of satellites, the fact that SUP usually paddle on open water makes it ideal for GPS analysis. GPS has been

used to quantify velocity in swimming with the authors suggesting that the utilisation of GPS is advantageous for outdoor training environments to better inform athletes, coaches and sport scientists (Beanland, Main, Aisbett, Gastin, & Netto, 2014). Investigations of intra-stroke kayak velocity and acceleration have demonstrated a tendency to under-report both velocity and acceleration with a 5Hz unit (Janssen & Sachlikidis, 2010). Previous studies on rowing have encountered problems in analysing speed as the speed can vary by up to 2-3m/s during each stroke with 5Hz units, something which now should be mitigated with the use of the 15Hz units (B. T. Smith & Hopkins, 2012).

3.3 The Measurement of Cardiovascular Demand for Performance Analysis

Along with the ability to perform movement analysis, many modern GPS units are also fitted with heart rate monitoring capability. The quantification of heart rate via telemetry is used to monitor changes in the function of the cardiac system (Howley & Franks, 2003). Heart rate measurement is a useful way of quantifying physiological demand, adaptation and intensity of effort (Laukkanen & Virtanen, 1998). Heart rate can be determined in a number of ways; manually by palpation, via a stethoscope, or with electrodes on the chest wall which transmit a signal to an electrocardiograph or monitor which allows for direct signal display (S. Powers, K. & Howley, 2012). Recent improvements in technology now allows heart rate to be easily obtained across a variety of sports, with small, lightweight telemetry units readily available (Farley et al., 2011).

The very high reliability ($r=0.98$) and validity of these telemetry devices has been previously reported in the literature (Achten & Jeukendrup, 2003; Laukkanen & Virtanen, 1998), with Polar (Polar electro, Finland) being the most widely used amongst the scientific literature. Endurance athletes commonly use heart rate monitors as a training tool to monitor exercise intensity and recovery, they are also extremely useful to monitor and to plan training (Achten & Jeukendrup, 2003). Endurance training is known to significantly reduce heart rate both at rest and submaximal exercise at a given volume of oxygen consumption ($\dot{V}O_2$) (Achten & Jeukendrup, 2003).

As increases in exercise intensity challenge the hearts ability to meet the oxygen demands of the working muscles, a linear relationship exists between the exercise intensity and heart rate (S. Powers, K. & Howley, 2012). Therefore heart rate, $\dot{V}O_2$ and lactate concentration can be used to predict, monitor and estimate fitness levels (Achten & Jeukendrup, 2003). Heart rate response to exercise is dependent on a number of physiological factors including cardiovascular drift and hydration status. Likewise, environmental factors such as heat, temperature and altitude can have an effect on heart rate during exercise (Achten & Jeukendrup, 2003).

3.4 Field Based Performance Analysis in Water Based Sports

Papers on the use of GPS units in water based sports, using GPS as a means to quantify movement and cardiovascular demands and total distances covered can be seen in Table 4. Farley's paper examined both movement demands, breakdown of speed zones and total distance covered during an event (Farley et al., 2011). Another study on windsurfing found competitors averaged 12km with a standard deviation of over 5km (Perez-Turpin et al., 2009).

Author, Year	Sport	Equipment used	GPS Findings	Heart Rate Findings
Farley, 2011	Surfing	GPSports SPI10	Surfers travelled	Average HR – 139.7±11bpm.
		GPS & Polar T31 Heart Rate monitor.	1605±313.5m during the 20 minute event. Majority of time spend in lowest speed zone while paddling around (1-4km/hr) followed by paddling hard for waves (4.8-8km/hr)	Max HR - 190±12bpm. Surfers spent 60% of their time in 56-74% of their age predicted HRMax (high intensity).
Perez-Turpin, 2009	Windsurfing	FRWD W600 GPS unit & heart rate monitor.	Distances covered varied greatly between competitors despite being a set race distance (12784±5522.19m)	Average HR – 127.62±13.73bpm. Max HR - 180.46±26.92bpm

Table 4: GPS and heart rate monitoring from other sports.

As SUP increases in popularity and competitiveness, the importance of testing SUP athletes to provide information for both coaches and athletes increases in parallel. Recently surfing has undergone GPS analysis (Farley et al., 2011), however SUP is yet to be investigated. Research on windsurfing races have shown great variability in total distance covered by competitors (Perez-Turpin et al., 2009). It is well known that varying distances can be covered in running marathons when not taking the inside line (point to point strategy) and participants may significantly add additional distance and subsequently extra time to their race.

Race results and ultimately race time will depend upon extrinsic variables such as swell (direction and height), currents and wind and intrinsic variables such as the racing line chosen by the competitor and the power output and length of each stroke. As the SUP athlete alternates paddling on each side, the direction of the SUP can be affected while racing and results in non-linear movements as the competitor propels themselves forward. Often the side chosen to paddle on is dictated by the extrinsic variables encountered during the event.

Along with the effect of intrinsic and extrinsic variables on SUP marathon races, heart rate intensities during SUP competition are unknown therefore limiting competition preparation and training. There is clearly a gap in the literature and the investigation of a distance event via GPS and HR telemetry units is clearly warranted. Therefore the purpose of this study was to gain an insight into the physiological demands associated with a SUP distance event to aid in athlete preparation and to assist coaches in planning conditioning and race tactics.

PAPER 1

A PERFORMANCE ANALYSIS OF A STAND UP PADDLE BOARD MARATHON RACE

**Schram, B., Hing, W., Climstein, M. (2015) A performance analysis
of a stand up paddle board marathon race. *Submitted to the
International Journal of Aquatic Research and Education***

Introduction

Stand up paddle boarding (SUP) is new sport and recreational activity, which is increasing in popularity around the world due to its proposed fitness, core strength benefits and enjoyment (Hammer, 2011). Stand up paddle boarding is a hybrid of surfing and paddling in which participants can either distance paddle and/or surf waves (Walker et al., 2010). At present there is no scientific literature available regarding the performance aspect of SUP.

SUP is an outdoor activity in which the participant maintains a standing position on a board similar to a surfboard however stand up paddle boards are longer in length (~8-15ft), thicker (4-8in) and wider (26-31in) than traditional surfboards. The participant propels the board across the surface of the water by the use of a long single-bladed paddle alternating sides ad libitum. The first official SUP race was held in 2004 along with the first SUP competitors entered in the famous Molokai to Oahu open ocean race in 2006. Recognition as a world competitive sport from the

International Surfing Association was obtained in 2012 when the first SUP World Championships were held in Peru.

As SUP increases in popularity and competitiveness, the importance of testing SUP athletes to provide information for both coaches and athletes increases in parallel. Although the majority of physiological testing of athletes is performed under highly-controlled laboratory conditions, these are often not sport specific conditions (Larsson, 2003). With the continued improvement of GPS technology, real-time sporting analysis may now occur in the field.

The use of global positioning systems (GPS) has recently been identified as a means to monitor physical activity of an athlete, giving such data as position, distance and speed in the field. GPS can be used in conjunction with other measurements such as a portable metabolic gas analysis system and telemetry heart rate to enable comparisons to be drawn between the subjects physical activity and physiological response (Larsson, 2003).

Quantifying movement patterns in sport is important for coaches and athletes to develop sport specific conditioning programs. Global positioning system analysis allows more accurate in situ analysis of work rate analysis than traditional video analysis, which has a propensity to erroneously categorise intensities whilst also being highly laborious to analyse (Cunniffe et al., 2009).

The reliability of GPS is dependent upon the units sampling rate, velocity, duration of the task and type of task (Aughey, 2011). Previous studies have used 1,5 and 10Hz units with authors suggesting that the higher the sampling rate of these units, the more valid GPS becomes for measuring distance and speed (Castellano et al., 2011). Comparisons between 5 and 10Hz units have found that the 10Hz units were two to three times more accurate and six times more reliable than the 5Hz devices for measuring instantaneous velocity (Varley et al., 2012). Recently 15Hz GPS units have been developed which would potentially further increase both the validity and reliability of these units.

Other sports have utilised such technological developments in the last 10-15 years as GPS units become more reliable and portable. Improvements in technology have seen the availability of GPS systems to coaches and athletes to gain a more in depth understanding of their training and competition habits (Cunniffe et al., 2009). It is not uncommon to see international sports

monitored for training load, heart rate and movement patterns in a wide range of sports from Australian rules football to horse racing (Kingston et al., 2006; Wisbey et al., 2010).

Although some sports have encountered difficulty in ensuring an unobstructed view of satellites, the fact that SUP is conducted on open water makes it ideal for GPS analysis. Previous studies on rowing have encountered problems in analysing speed as the speed can vary by up to 2-3m/s during each stroke with 5Hz units, a problem which should now be mitigated with the use of the 15Hz units (B. T. Smith & Hopkins, 2012).

Recently surfing has undergone a GPS analysis (Farley et al., 2011), however SUP is yet to be investigated. Previous research on windsurfing races have shown great variability in total distance covered by competitors. It is well known that varying distances can be covered in running marathons when not taking the inside line (point to point strategy) and participants may significantly add additional distance and subsequently extra time to their race.

Race results and ultimately race time will depend upon extrinsic variables such as swell (direction and height), currents and wind and intrinsic variables such as the racing line chosen by the competitor and the power output and length of each stroke. As the SUP athlete alternates paddling on each side, the direction of the SUP can be affected while racing and results in non-linear movements as the competitor propels themselves forward. Often the side chosen to paddle on, is dictated by the extrinsic variables encountered during the event.

Along with the effect of intrinsic and extrinsic variables on SUP marathon races, heart rate intensities during SUP competition are unknown therefore limiting competition preparation and training. There is clearly a gap in the literature and the investigation of a distance event via GPS and HR telemetry units is clearly warranted. Therefore the purpose of this study was to gain an insight into the physiological demands associated with a SUP distance event to aid in athlete preparation and to assist coaches in planning conditioning and race tactics.

Methods

A total of ten elite ranked (2-10 nationally, 5-24 internationally) SUP participants (34.78 ± 11.49 yrs) recruited from the Stand Up Paddle Surfers Australia volunteered to participate in this study. SUP participants were competing in the Australian titles in the marathon distance event as a qualifying event for the Australian team for the world championships. This study was approved by the University Human Research Ethics Committee (RO-1550) and each participant formally consented prior to taking part in the study.

Each participant was familiarised with the GPS device and instructed where to place both the heart rate transmitter strap and GPS receiver unit (GPSports HPISPU, 15Hz, dimensions = 74mm x 42mm x 16mm, weight = 67grams). The units were placed in a water proof zip-lock bag on the front or back pocket of the participant's hydration packs worn on the chest. The point to point distance of the SUP marathon event was 12.7 km (7.89miles) and the course headed in a southerly direction to an inlet 11.3km (7.02miles) away with a subsequent 1.4km (0.87miles) paddle through a river mouth and into the river in a westerly direction.

The environmental conditions on the day involved a 0.89m low tide, 11 knot average northerly wind with 14 knot gusts, 0.5m of ENE swell with a 5 sec wave period at the beginning of the race. All GPS units were activated 10 minutes prior to the start of the event to ensure they linked up with the required number of satellites ($n > 3$). Following completion of the event, raw data was downloaded using specialised software and the pre and post-event periods were eliminated from data analysis.

Statistical Analysis

Descriptive statistics were used to determine means, ranges and standard deviations of each of the results obtained. A Pearson correlation analysis between distance covered and position over the line was also performed. All data analysis was conducted using Statistical Package for the Social Sciences (SPSS, version 20.0, Armonk, NY, USA).

Results

Nine out of the ten participants finished the race with one participant having to withdraw prematurely due to injury (muscle strain). The SUP participant individual course plots are shown in Figure 5, where at the widest point while in the Open Ocean, participants were spread 660m apart from one another. Times varied from 1:15.1 to 1:39.9 for the completion of the course as seen in Table 5.

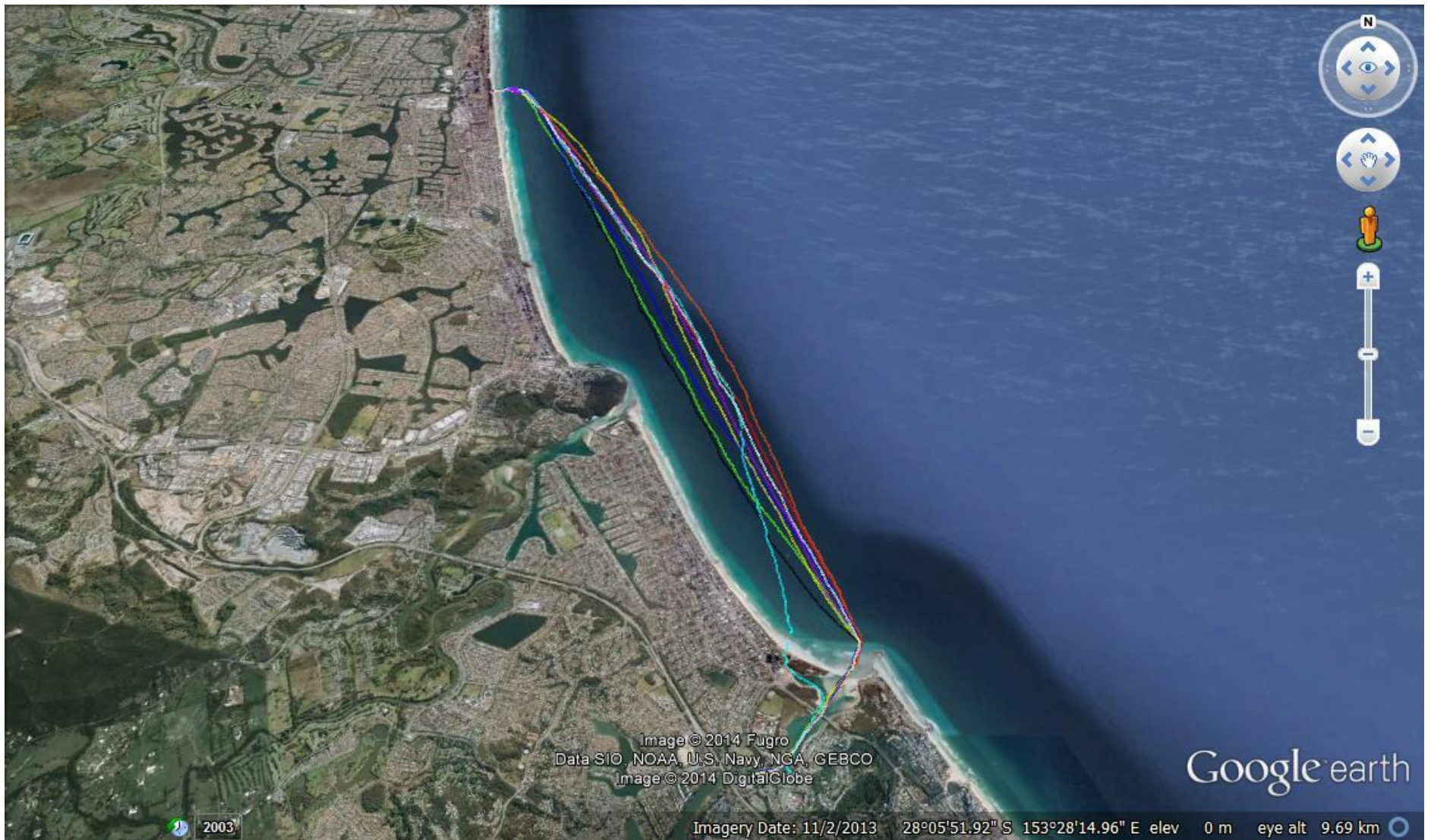


Figure 5: GPS plot of individual courses taken during the race.

Position	Race Time (mins)	Distance covered (m)
1	01:15.1	13522.60
2	01:16.5	13563.00
3	01:17.3	13491.50
4	01:22.4	13419.90
5	01:22.6	13716.00
6	01:24.1	13566.77
7	01:25.3	13340.80
8	01:27.2	13587.30
9	01:39.9	13874.00

Table 5: Participants place across the line and distance covered.

The group, male and female averages displayed in Table 6 shows that participants covered an average distance of 13.56km with a range of 13.34km to 13.87km. Peak heart rate recorded ranged from 168bpm (98%HRmax) to 208bpm (103%HRmax). Peak speeds recording during the event was 26.39km/hr by the winning female and the highest average speed recorded being 10.8km/hr (3.0m/s) from the winning male. There was a moderate, positive correlation between the participants distance covered and their position over the line. This relationship was not significant ($p=0.385$).

Parameter	Group (n = 9)	Males (n = 6)	Females (n = 3)
Age (yrs)	34.78 (11.49)	31.11 (12.32)	41.67 (6.43)
Height (cm)	172.14 (7.50)	176.38 (4.55)	163.67 (3.51)
Weight (kg)	72.03 (10.13)	77.67 (6.85)	60.77 (2.70)
BMI (kg/m ²)	24.17 (2.55)	24.88 (2.70)	22.73 (1.79)
Years Competition (yrs)	5.39 (1.65)	5.08 (1.91)	6.00 (1.00)
Ranking	5-24 International 2-10 National	5-24 International 5-10 National	6-24 International 2-5 National
Course completion time (min)	83.37 (7.47)	79.87 (4.10)	90.40 (8.37)
Course distance covered (m)	13564.65 (157.05)	13508.97 (128.44)	13676.02 (171.76)
Peak speed (km/hr)	21.27 (0.70)	20.95 (2.24)	21.90 (3.91)
Average speed (km/hr)	9.78 (0.70)	10.13 (0.53)	9.07 (0.41)
Distance per minute (m)	163.21 (12.68)	169.00 (9.19)	151.63 (11.43)
Average heart rate (bpm)	168.56 (9.79)	172.00 (10.32)	161.67 (3.21)
Peak heart rate (bpm)	187.00 (13.52)	194.17 (9.87)	172.67 (5.03)

Table 6: Participant demographics and GPS results. Values presented are mean (\pm SD).

As seen in Table 7, athletes spent 89.31% of their race within 80-100% of their age predicted HRmax. Athletes were predominately in the 5-10km/hr zone followed by the 10-15km/hr zone. Minimal data points were recorded in the zone 1, zone 4 and zone 5.

	Velocity (km/hr)	Time (s)	Time (%)	% HR Max	% of race
Zone 1	0-5	4648 (36.58)	0.90% (0.59%)	60-70%	4.84% (7.60%)
Zone 2	5-10	3353.83 (958.36)	66.06% (13.03%)	70-80%	3.95% (4.38%)
Zone 3	10-15	1567.12 (527.09)	32.30% (12.89%)	80-90%	27.46% (34.02%)
Zone 4	15-20	34.03 (21.94)	0.71% (0.50%)	90-100%	61.85% (32.12%)
Zone 5	>20	1.38 (1.89)	0.03% (0.04%)	>100%	1.09% (4.50%)
Total	-	5002.95 (447.86)	100%	-	100%

Table 7: Time spent in velocity and heart rate zones for the race. Values presented are mean (\pm SD).

An example of an individual participant heart rate and speed trace can be seen in Figure 6. Incremental increases in cardiovascular demand as seen by elevation of heart rate can be seen from the start of the race with maintenance of 80-100% of the participants HRmax for the duration of the race. Speed is seen to be more variable with peak speed being at the point when participants were paddling in a westerly direction, enabling them to ride waves.

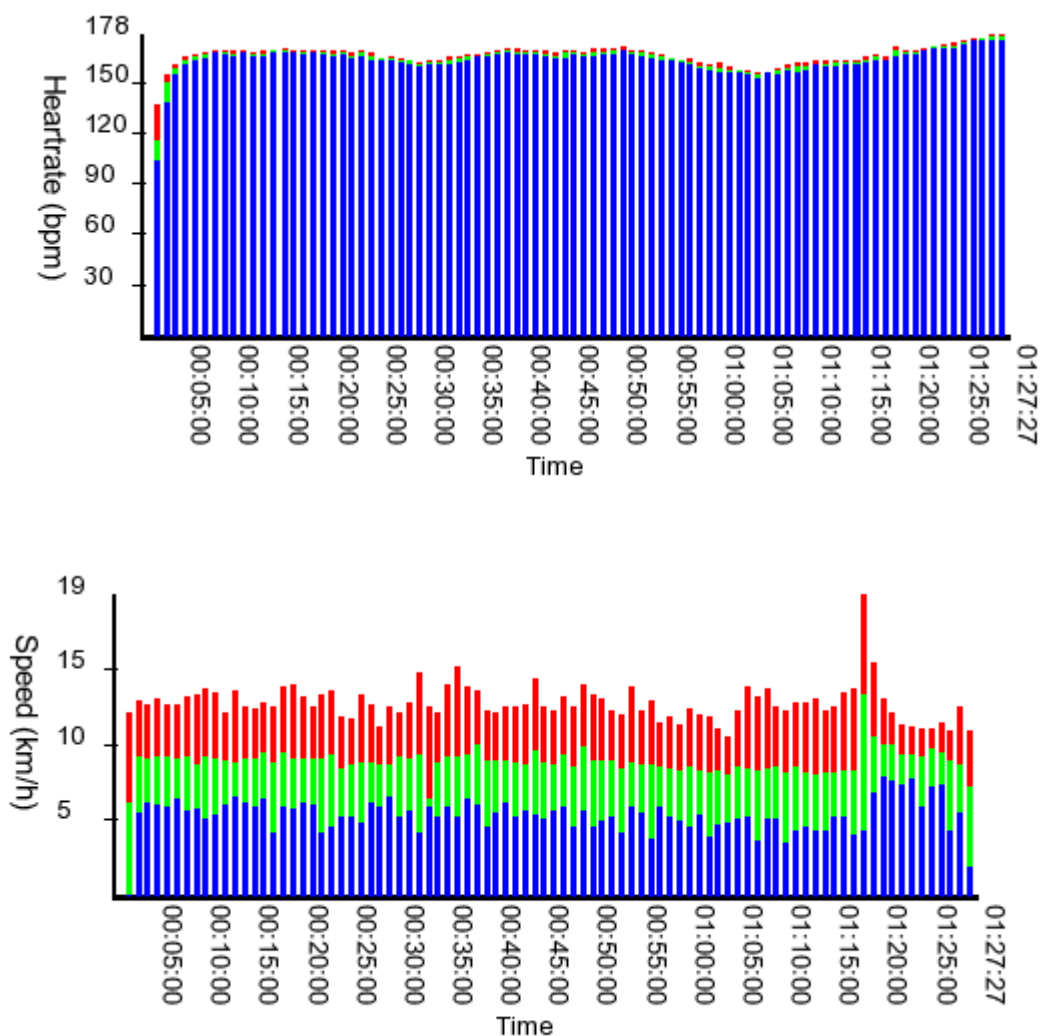


Figure 6: Individual heart rate and speed results showing minimum (blue), average (green) and maximum (red).

Discussion

Previously, no scientific literature was available on the physiological (HR) demands and time motional analysis of a marathon SUP event. This study aimed to provide an understanding of the requirements of such a race. The majority of times, participants were in steady state with regard to speed and HR however peak speed occurred when the participant was paddling toward shore and when catching open ocean swell lines, the latter being highly advantageous to achieving a shorter race time.

The low correlation ($r=0.384$) between the distance covered by SUP participants and the race results demonstrated that SUP race tactics are critical in race results, the shortest distance covered was recorded by a participant who was the seventh across the line. The utilisation of tactics may also explain the spread of the field up to 660 meters during this event. The participants finishing in higher places were able to obtain a higher average speed through the duration of the event by regularly catching small waves and utilizing swell lines in the direction of the wind on the day. Although this strategy may result in a SUP participant paddling a greater total distance, the average speed of the participant remained high, therefore ensuring completion of the event in the shortest amount of time.

This variation in total distance covered due to environmental conditions is similar to what has been previously published in windsurfing events with distances covered having a standard deviation of over 5km (Perez-Turpin et al., 2009). This is primarily due to the participants seeking out the best environmental conditions to maximise their speed across the water. This is most likely the explanation for the variation of over 500m in distance covered between athletes in this race.

The heart rate variability in this race is partly due to the variation in ages (18-55yrs) of the SUP participants. The national competition is divided into open men's and women's, over 40's and over 50's. Although age limits maximum heart rate, all athletes were able to maintain their heart rates above 150bpm for the duration of the race. The lowest heart rates were seen at the beginning of the race where they increased rapidly and were maintained for the majority of the race at 80-100% of their HRmax.

Global positioning analysis of this sport is ideal in populated areas due to accessibility, the ability to closely monitor the athlete and availability of satellites for the GPS units. The initial aim of this study was to investigate the Molokai to Oahu challenge in which SUP athletes paddle 52km of Open Ocean from island to island each year in Hawaii. Although initially the GPS units worked well, the remoteness of the location resulted in a drop out from satellite coverage. The 15Hz units, despite being more accurate, require a greater number of satellites to be able to log data. It is suggested for future studies, researchers ensure adequate satellite coverage in the location of the SUP events.

These findings are applicable for both SUP athletes and coaches to assist with sports specific training sessions and informed decisions with regard to race tactics. It is clear that marathon SUP races have a large technical component which can influence results. Extrinsic variables on the day can dictate optimum course which can maximise speed during a race and therefore there are subsequently wide variations in distances covered during a race. Marathon SUP races require heart rate elevation to near maximal levels for the duration of the race.

3.5 Summary

It can be seen that stand up paddle boarding requires a high level of cardiovascular demand with aerobic and anaerobic fitness being important for competition seen by the high heart rate requirement and also the need to be able to catch waves for maximal propulsion. It also appears as though muscular strength and endurance are important due to the duration of the event. A high level of balance would also be required to complete a race due to the dynamic environment in which it is performed. Extrinsic variables on the day of the race appear to affect race results with study 1 demonstrating that the shortest distance covered doesn't necessarily mean the shortest time. Athletes should be aware of the effects of currents, wind, tide and swell to maximise their tactical preparation and minimise race times.

Chapter 4

Methodological design to assess Stand Up Paddle Boarders

PREFACE:

The areas identified as being of importance to SUP appear to be fitness, balance and strength. Chapter 4 is designed to explore methods of assessing those areas deemed to be of importance to SUP as seen in Figure 7. It aims to explore the various ways of assessing physiological, musculoskeletal and balance profiles reported previously for application to SUP. As minimal research has been conducted previously, this section 4.2 of this chapter will firstly provide physiological figures from other water based sports for direct comparison to SUP. Study 2 is found in this section which is designed to test the correlation of laboratory and field based measures of physiological function to ensure confidence in laboratory based measures in future studies.

Although minimal scientific study has been performed on SUP, the use of unstable surface training has received attention in regards to its effect on both the musculoskeletal and balance systems. The concept and research around instability training is therefore presented in section 4.3. The importance of an effective musculoskeletal system and its assessment via electromyography is explored in section 4.4. This section will also highlight the specific muscles of interest to this investigation along with their importance and relationship to rehabilitation. A methodological study assessing these key muscles via EMG, whilst paddling a SUP ergometer is then presented.

In section 4.5, following the methodological issues associated with electromyography for investigation in SUP, alternative means of assessing the musculoskeletal system are explored. Finally the assessment of both static and dynamic balance in sports published throughout the literature will be explored in section 4.6 for future application to a SUP population.

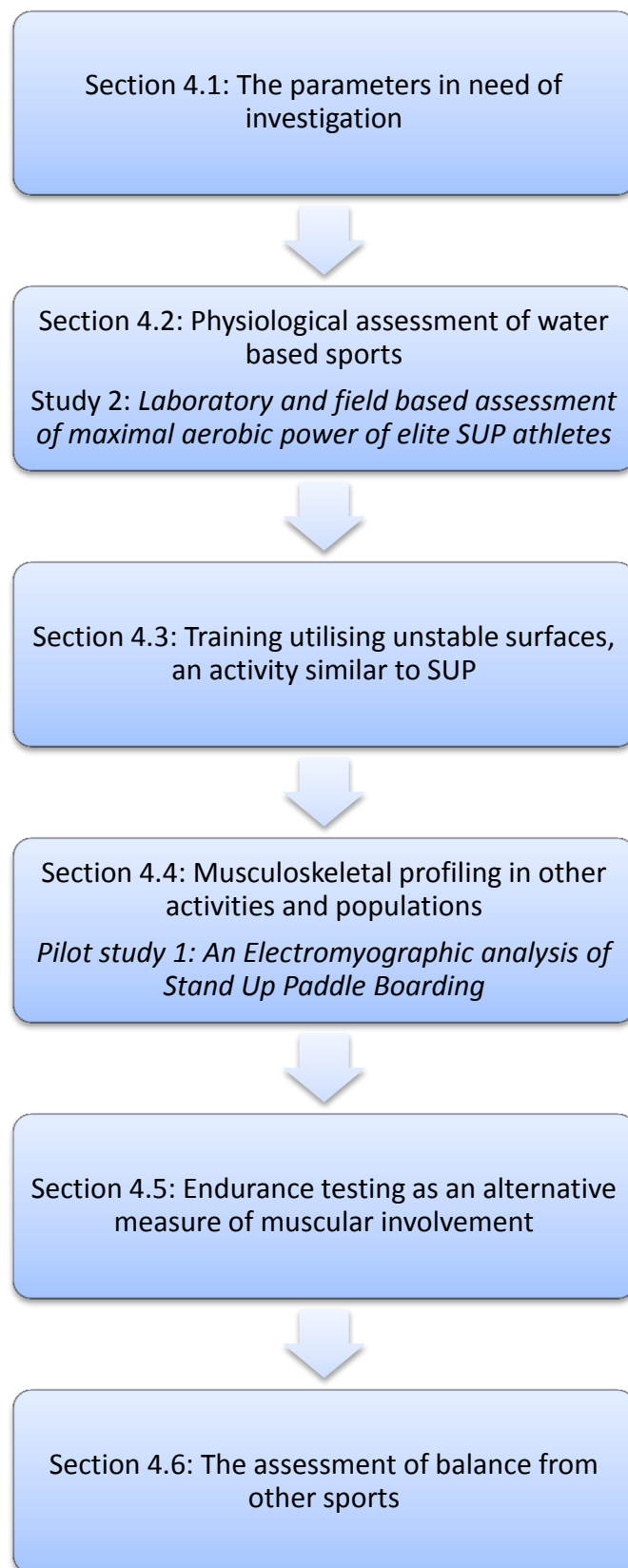


Figure 7: An overview of Chapter 4

4.1 The Parameters In Need Of Investigation

Chapter 3 has offered insight into the factors important for SUP as a sport. Participants in races are required to have high levels of aerobic and anaerobic fitness, trunk muscle strength, muscle endurance and also balance. The assessment of these areas has been performed previously in other sports and will be explored for use in a SUP population. This information in other sports is primarily used to enhance education, for planning and training for success and development of its athletes. The understanding of oxygen consumption, respiration, heart rates, velocity, acceleration, force, changes in direction and positional information are required in elite training and coaching (Zhang et al., 2004). The profiling of athletes in sport is required to aid athlete selection, development and placement and in program design.

Previous studies have profiled a range of aspects in sports including morphological characteristics (Ackland, Ong, Kerr, & Ridge, 2003), injuries (McCarthy, Voos, Nguyen, Callahan, & Hannafin, 2013), physiological profiles (Franchini, Vecchio, Matsushigue, & Artioli, 2011), strength profiles (Chaabène, Hachana, Franchini, Mkaouer, & Chamari, 2012) and balance ability (Hrysomallis, 2011). As there is only two previous studies identified in the literature, there is a void of information on the potential benefits of participation in SUP. Therefore sports of similar characteristics were utilised for comparison and reviewed. Some of the sports deemed similar to SUP are water sports such as canoeing, kayaking, dragon boat racing and surfing.

In a similar manner to surfing, it is assumed that SUP involves intermittent muscular endurance and anaerobic power of the upper body for paddling propulsion, an exceptional level of cardio-respiratory endurance and dynamic balance and flexibility (Frank, Zhou, Bezerra, & Crowley, 2009). As seen in study 1, maintenance of elevated heart rates for the duration of SUP events is required highlighting the importance of a high level of aerobic fitness amongst its participants. When surfing a SUP or attempting to catch waves during a race, anaerobic power is also an important physiological determinant to enable the individual to match the speed of a wave.

Similar to kayaking, SUP paddling requires a powerful and skilful paddler to maximise upper body muscular power, to provide forward propulsion and negate as much of the drag forces as possible (Michael et al., 2009). It is with greater power commensurate with decreased drag that

speed across the water is increased; therefore it is assumed that with greater upper body paddling power, a SUP rider should be faster across the water.

Due to the dynamic nature of the sport, it is assumed that the constant postural challenge would provide a means of enhancing dynamic balance ability. The assessment of which has been studied in other sports and amongst other populations. It is therefore assumed that a proficient SUP athlete would possess a high level of dynamic postural control. The areas therefore deemed important to SUP for this study are the physiological profile including aerobic and anaerobic fitness, strength of the trunk musculature and static and dynamic balance.

4.2 Physiological Assessment in Water Based Sports

4.2.1 Aerobic Fitness Testing In Water Based Sports

Physiological exercise testing offers a unique opportunity to study the cellular and cardiorespiratory system responses under precisely controlled metabolic stress (Wasserman, 1999). One of the most fundamental measurements in exercise physiology is maximal oxygen uptake ($\dot{V}O_{2max}$) (Wasserman, 1999). The measurement of oxygen utilization, carbon dioxide production and ventilation allows the non-invasive evaluation of maximal aerobic capacity (L. D. Hodges, Brodie, & Bromley, 2005).

Training induced changes in aerobic power have been measured in a variety of sports with the use of a $\dot{V}O_{2max}$ test (Pelham & Holt, 1995b). Sports similar to SUP such as rowing, kayaking, surfing, dragon boat racing and canoeing were deemed to have similar physiological demands to SUP. Previous surfing studies have included the use of prone arm paddling (Mendez-Villaneuva & Bishop, 2005), swim bench ergometers (Loveless & Minahan, 2010a), arm cranking in prone and tethered board paddling (Lowdon, Bedi, & Horvath, 1989) .

To date, five articles have tested the maximal aerobic capacity of surfers (Farley, Harris, & Kilding, 2012; Loveless & Minahan, 2010a; Lowdon et al., 1989; Meir, Lowdon, & Davie, 1991; Mendez-Villaneuva & Bishop, 2005) and can be found in Table 8. Relative aerobic capacities previously published in surfing have ranged from 37.8ml/kg/min to 54.2ml/kg/min. Although research data for surfing is limited, there appears to be no relationship between aerobic power and competitive

surfing status (Loveless & Minahan, 2010a). This could possibly be due to recreational surfers spending the same amount of time in the water as competitive surfers and therefore gaining the same training stimulus (Lowdon, 1983). Another contributing factor for this finding is that paddling during surfing competitions has been estimated to be as low as 44%, therefore not having adequate stimulus for the aerobic energy system to adapt (Loveless & Minahan, 2010b).

Author	Subjects	Testing Mode	$\dot{V}O_{2\text{ peak}}$ (ml/kg/min)	Aerobic Power (W)
Loveless & Minahan, 2010 (Loveless & Minahan, 2010b)	n=8 (18±2yrs) Recreational Surfers	Swim bench ergo	37.8 ± 4.5	199 ± 24
Loveless & Minahan, 2010 (Loveless & Minahan, 2010b)	n=8 (18±1yrs) Competitive Surfers	Swim bench ergo	39.5 ± 3.1	199 ± 45
Meir, 1999 (Meir et al., 1991)	n = 6 (21.2 ± 2.8yrs) Recreational Surfers	Swim bench	54.2 ± 10.2	
Lowdon, 1989 (Lowdon et al., 1989)	n = 12 (20.7 ± 1.2yrs) Competitive Surfers	Tethered board Paddling Arm Crank	40.4 ± 2.9/ 41.6 ± 4.0	
Mendez-Villaneuva, 2005 (Mendez-Villaneuva & Bishop, 2005)	n = 7 (25.6 ± 3.4yrs) European Level Surfers	Modified Kayak Ergometer	50.0 ± 4.7	154 ± 37
Mendez-Villaneuva, 2005 (Mendez-Villaneuva & Bishop, 2005)	n = 6 (26.5 ± 3.6yrs) Regional Level Surfers	Modified Kayak Ergometer	47.9 ± 6.3	118 ± 27
Farley, 2012 (Farley et al., 2012)	n = 8 (20.4 ± 6.6yrs) National Level Surfers	Modified Kayak Ergometer	44 ± 8.26	158 ± 20.7

Table 8: Results of aerobic power output from surfing studies (Modified from Farley, 2011).

Other water based sports excluding surfing have assessed kayaking, canoeing and dragon boat paddling utilised kayak ergometers (Hahn, Pang, Tumilty, & Telford, 1988), arm crank ergometers (Singh, Singh, & Sirisinghe, 1995) and custom made ergometers (Marrin & Pout, 2007). Papers on kayaking, canoeing, rowing, swimming and dragon boat racing can be found in Table 9.

Ergometers have been proven to be quite useful to assess peak power and $\dot{V}O_{2\max}$ which are valuable measures of rowing performance (B. T. Smith & Hopkins, 2012). Olympic kayakers have been estimated to use aerobic metabolism 73-85% of the time for distances of 500 and 1000m respectively (Michael, Rooney, & Smith, 2008). Figures from the literature published on kayaking maximal oxygen uptake was reported to range from 44.81- 52.6ml/kg/min for women and 47.5 - 61.4ml/kg/min for men.

Sport	Author	$\dot{V}O_{2\text{ peak}}$ (ml/kg/min)	Aerobic Power (W)
Kayaking	Tesch, 1983 (Tesch, 1983)	58.8	-
	Hahn et. al., 1988 (Hahn et al., 1988)	58.5	-
	Fry & Morton, 1991 (Fry & Morton, 1991)	58.9	-
	Billat et. al., 1996 (Billat et al., 1996)	53.8	239
	Bishop, 2000 (women) (Bishop, 2000)	44.81	175
	Buglione, 2011 (men) (Buglione, Lazzer, Colli, Introini, & Di Prampero, 2011)	61.4	-
	(women)	52.6	-
	Forbes, 2011 (Forbes & Chilibeck, 2007)	47.5	-
Canoeing	Hahn et.al., 1988 (Hahn et al., 1988)	44.2	-
	Bunc & Heller, 1991 (Bunc & Heller, 1991)	51.9	-
	Buglione, 2011(Buglione et al., 2011)	61.8	-
Rowing	Di Prampero et. al., 1971 (di Prampero, Cortili, Celentano, & Cerretelli, 1971)	58.8	-
	Secher, 1990 (Secher, 1990)	68.2	-
	Lakomy & Lakomy, 1993 (Lakomy & Lakomy, 1993)	60	-
	Jurimae, 2000 (Jurimae, Meaetsu, & Jurimae, 2000)	61.5	-
	Gerzevic, 2011 (Gerzevic, Strojnik, & Jarm, 2011)	62.88	371.67
Swimming	Lavoie et.al., 1981 (Lavoie, Taylor, & Montpetit, 1981)	58.4	-
	Billat et.al., 1996 (Billat et al., 1996)	59.6	-
	Roels et. al., 2005 (Roels et al., 2005)	58.4	-
Dragon Boat Racing	Singh, 1995 (Singh et al., 1995)	42.3	-
	Marrin, 2007 (Marrin & Pout, 2007)	44.8	-
	Ho, 2012 (Ho, Smith, Chapman, Sinclair, & Funato, 2012)	50.2	195

Table 9: Results from assessment of aerobic power from other sports (Modified from Michael, 2008).

The majority of studies on rowing have identified the maximum consumption of oxygen ($\dot{V}O_{2max}$) and the maximum aerobic power as the best predictors of rowing performance (Izquierdo-Gabarren, de Txabarri Expósito, de Villarreal, & Izquierdo, 2010). Competitive Olympic rowing is regarded as an endurance sport so a close relationship between rowing performance and aerobic capacity has been demonstrated (Cosgrove, Wilson, Watt, & Grant, 1999; Kramer, Leger, Paterson, & Morrow, 1994; Yoshiga & Higuchi, 2003). Maximal oxygen consumption values of 58.8 to 68.2 ml/kg/min have been reported with the use of ergometers, although it has been argued that in rowing, the use of ergometers does not reflect the skill component of performance on water (McNeely, 2011; B. T. Smith & Hopkins, 2012).

Fitness testing of swimmers has been performed both on swim ergometers and also in the pool with the use of snorkels attached to portable gas analysis systems. Many swimming studies have identified technique and economy as being more important to performance rather than aerobic fitness (Burnley & Jones, 2007; Reis, Alves, Bruno, Vleck, & Millet, 2012). Relative maximal aerobic capacities of 54.8 and 59.6ml/kg/min have been reported from the literature thus far.

With the advancement of sport science technology, coaches and participants today can now have access to field based data on athletes work rates, can evaluate training loads, movement patterns and activity profiles (Achten & Jeukendrup, 2003; Larsson, 2003). Utilisation of heart rate monitors, GPS units and portable gas analysis systems now means that sport scientists can test and measure parameters of athletic performance in controlled scientific laboratories and also in the field.

4.2.2 Methodological Design for Physiological Testing Of Stand Up Paddle Boarders.

As SUP has not been investigated from a physiological perspective in regards to aerobic fitness, methodological issues are raised. An ideal physiological test is one which accurately and reliably assesses the specific energy systems of the musculature involved in that particular sport (Pelham & Holt, 1995b). To adhere to the principle of specificity, in addition to laboratory testing, field testing for aerobic power on a stand up paddle board is highly desirable. This allows comparison between testing in a laboratory under tightly controlled conditions and actual SUP performance on water.

Recent advances in technology have allowed for more compact, light-weight and portable systems such as the Cosmed K4b². This portable gas analysis system can be seen in Figure 9 on page 77. The development of such systems has allowed field testing to gain a greater understanding of the metabolic demands placed on the body during various modes and intensities of exercise in the environment in which they are normally performed (Duffield, 2004). The K4b2 system has been shown to be acceptable for measuring oxygen uptake over a wide range of exercise intensities (Duffield, 2004) and shows strong correlation ($r=0.926$) to metabolic carts inside laboratories (Pinnington, Wong, Tay, Green, & Dawson, 2001). The K4b2 has been reported to be reliable for sport specific upper body ergometry for measurement of peak physiological responses of outrigger canoeists (Leicht, Sealey, Sinclair, & Spinks, 2010).

An indication of the aerobic capacity of elite SUP athletes provides a guideline for an individual wanting to succeed in competitive SUP. The measurement of aerobic fitness of internationally and nationally ranked SUP athletes has yet to be quantified, leaving a gap in the scientific literature. A study was therefore designed to assess the correlation to laboratory based assessment of aerobic power of SUP athletes and field based measurements. The purpose of this study was to assess internationally and nationally ranked SUP athletes in the laboratory under tightly controlled conditions, then compare the result to a field based assessment with a portable gas analysis system. A SUP specific ergometer was sourced to replicate the activity in the laboratory and can be seen in Figure 8.



Figure 8: The SUPERgo utilised for the laboratory based testing.

PAPER 2

LABORATORY AND FIELD BASED ASSESSMENT OF MAXIMAL AEROBIC POWER OF ELITE SUP ATHLETES

Schram, B., Hing, W., Climstein, M. (2016) Laboratory and field based assessment of maximal aerobic power of elite SUP athletes. *As accepted for publication in International Journal of Sports Physiology and Performance, ©Human Kinetics*
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Introduction

Stand up paddle boarding (SUP) is a new sport and recreational activity, which is increasing in popularity around the world due to its proposed health and fitness benefits and enjoyment (Hammer, 2011). Stand up paddle boarding is a hybrid of surfing and paddling in which participants can either distance paddle and/or surf waves (Walker et al., 2010). Many websites anecdotally advocate the use of SUP to increase strength, fitness, core stability, balance and decrease back pain. However our recent review of the literature utilising the search terms “SUP”, “Stand Up Paddle Boarding” and “Stand Up Paddle” of CINAHL, SPORTDiscus, EMBASE & Medline found no scientific evidence to substantiate these proposed benefits.

An ideal physiological test is one which accurately and reliably assesses the specific energy systems of the musculature involved in that particular sport (Pelham & Holt, 1995b). To adhere to the principle of specificity, in addition to laboratory testing, field testing for aerobic power on a stand up paddle board is highly desirable. This allows comparison between testing in a laboratory under tightly controlled conditions and actual SUP performance on water.

Recent advances in technology have allowed for more compact, light-weight and ambulatory pulmonary gas analysis system (Cosmed K4b2, Rome, Italy). The development of such systems has allowed field testing to gain a greater understanding of the metabolic demands during various modes and intensities of exercise in the environment in which they are normally performed (Duffield, 2004).

An indication of the aerobic capacity of elite SUP athletes provides a guideline for an individual wanting to succeed in competitive SUP. The measurement of aerobic fitness of internationally and nationally ranked SUP athletes has yet to be quantified, leaving a gap in the scientific literature. Therefore, the purpose of this study was to assess internationally and nationally ranked SUP athletes in the laboratory under tightly controlled conditions, then compare the result to a field based assessment with a portable gas analysis system.

Methods

Subjects

A total of 10 elite competitive (6 males & 4 females) SUP athletes were recruited from the Stand Up Paddle Surfers Association (Gold Coast, QLD, Australia). Of the elite competitors, six were rated amongst the top ten in the world and the remaining athletes were currently competing in the national competition of SUP in Australia. For inclusion, athletes were without a history of back pain and were free from any physical and psychological impairment. The study was approved by the University Human Research Ethics Committee (RO-1550) and each participant formally consented to taking part in the study.

Design

This was a comparative study in which athletes were tested for maximal aerobic power in the field with a portable gas analysis system and subsequently in the laboratory under tightly controlled conditions. The primary aims of this study were to assess elite SUP athletes for their maximal aerobic power on an SUP ergometer in a laboratory and compare the results to other water based athletes. The secondary aim was to compare the laboratory result to a field based measurement utilising a portable gas analysis system.

Methodology

Athletes attended the Water Based Research Unit laboratory where a continuous graded exercise test on a specialised SUP ergometer (KayakPro SUPergo, Miami, FL, USA) was used to determine maximal aerobic power (relative and absolute). Maximal aerobic power ($\dot{V}O_{2max}$) was determined using an automated expired gas analysis system (Parvomedics TrueOne 2400 metabolic system, East Sandy, Utah, USA) which was calibrated (gas analyzers and ventilation) prior to each test. The expired gas analysis system meets Australian Institute of Sport accreditation standards for precision and accuracy. The gas analysis software was configured to breath-by-breath for collection however $\dot{V}O_{2max}$ was determined from the average of 30 seconds of max data collected.

The SUP ergometer $\dot{V}O_{2max}$ protocol involved the athletes starting at an initial power output of 5W with a 5W increase each minute until volitional exhaustion. The ergometer was connected to a laptop with a software program (eMonitor Pro, KayakPro, Miami, FL, USA) which gave data on stroke rate, stroke length, total distance, power output and average velocity. The athletes were instructed to paddle as per normal, free to alternate paddling on each side ad libitum. Heart rates were monitored throughout the test with a 12 lead ECG via telemetry (Figure 9). A portable gas analysis system (Cosmed K4b2, Rome Italy) previously validated for field assessment of $\dot{V}O_{2max}$ in a number of outside activities (Duffield, 2004), was utilized to assess expired concentrations of oxygen and ventilation (Figure 9). For comparison to laboratory findings, the athletes then completed a $\dot{V}O_2$ test whilst on flat water in a creek (tide neutral).



Figure 9: The ergometer and laboratory equipment and the K4b2 portable unit.

The protocol for the field based assessment of maximal aerobic power involved starting at 30 strokes per minute keeping cadence with a metronome played to the athletes through headphones attached to a portable media player (iPod). The metronome increased cadence by 5 strokes per minute every minute which the participant was to maintain until volitional fatigue. All water based $\dot{V}O_{2\max}$ tests were conducted within five days of the laboratory tests to ensure minimal physiological change to maximal aerobic fitness.

Statistical Analysis

All statistical analyses were performed using SPSS (Version 20) including mean and standard deviation calculations, while paired *t* tests were used to determine any significant differences between the two groups. Alpha was set at 0.05 *a priori*. A Pearson correlation analysis was performed to compare laboratory results to field results. A Bland Altman plot (Bland & Altman, 2003) was utilised to provide a graphical representation of the two different measurement techniques, with limits of agreement set at 95%.

Results

Table 10 displays that males were younger (-9.42%) but not significantly ($p=0.627$), significantly taller (+8.82%, $p=0.006$) and significantly heavier (+21.37%, $p=0.044$) than the female athletes. The overall group, and female body mass index (BMI) was within the healthy category with the males being classified as overweight despite being only slightly more than the females (+2.78%). This was assumed to be to a greater lean mass.

	Group (n=10)	Males (n=6)	Females (n=4)
Age (yrs)	35.8 (9.55)	34.50 (6.03)	37.75 (14.32)
Height (cm)	174.00 (0.45)	179.83 (6.91)	165.25 (4.27)
Weight (kg)	75.59 (11.44)	81.32 (6.41)	67.00 (12.66)
BMI (kg/m ²)	24.87 (2.42)	25.14 (1.36)	24.46 (3.77)
Body Fat (%)	15.87 (7.40)	11.13 (2.79)	22.98 (6.25)

Table 10: Participant demographics. Results expressed as mean (SD).

Field based results of maximal aerobic power for the group, were significantly higher (+5.28%, $p=0.037$) as compared to laboratory based results (Table 11). A significant ($p=0.000$) difference was found in peak speed measured in the field (+42.39%) compared to in the laboratory. There were no significant differences in maximal heart rate measured between the field and laboratory ($p=0.576$). Males had a significantly greater maximal aerobic power as compared to females in both the laboratory (47.59 ± 3.37 vs 36.61 ± 4.24 ml/kg/min, $p=0.002$) and in the field (49.68 ± 4.41 vs 39.18 ± 4.96 ml/kg/min, $p=0.008$). There were no significant differences between genders with regard to maximal ventilation (VE), respiratory exchange ratio (RER), or heart rate in the laboratory when compared to the field.

	Laboratory	Field
$\dot{V}O_{2\max}$ (ml/kg/min)	43.20 (6.67)	45.48 (6.96)*
V_E STPD (L/min)	118.09 (24.79)	123.63 (41.68)
Respiratory Exchange Ratio	1.13 (0.05)	1.16 (0.08)
Heart Rate (bpm)	180.9 (15.58)	183 (9.89)
Peak Speed (m/s)	2.17 (0.13)	3.09 (0.32)**

Table 11: Laboratory versus field based results of maximal aerobic power. * = $p=0.037$, ** $p=0.000$. Results expressed as mean (SD).

A high, positive correlation ($r=0.907$) was found between the absolute $\dot{V}O_{2\max}$ recorded in the laboratory and in the field with the portable gas analysis unit (Figure 10). The field measurement was higher in 80% of the subjects tested with only two subjects demonstrating higher $\dot{V}O_{2\max}$ values in the laboratory. The mean difference between the two samples was only -2.28 (2.95) ml/kg/min. A linear regression of the differences of the mean demonstrated that there was no proportional bias between the two measures ($p=0.785$). There was however, fixed bias ($p=0.037$) as the measurements in the field were consistently higher than the laboratory based measurement.

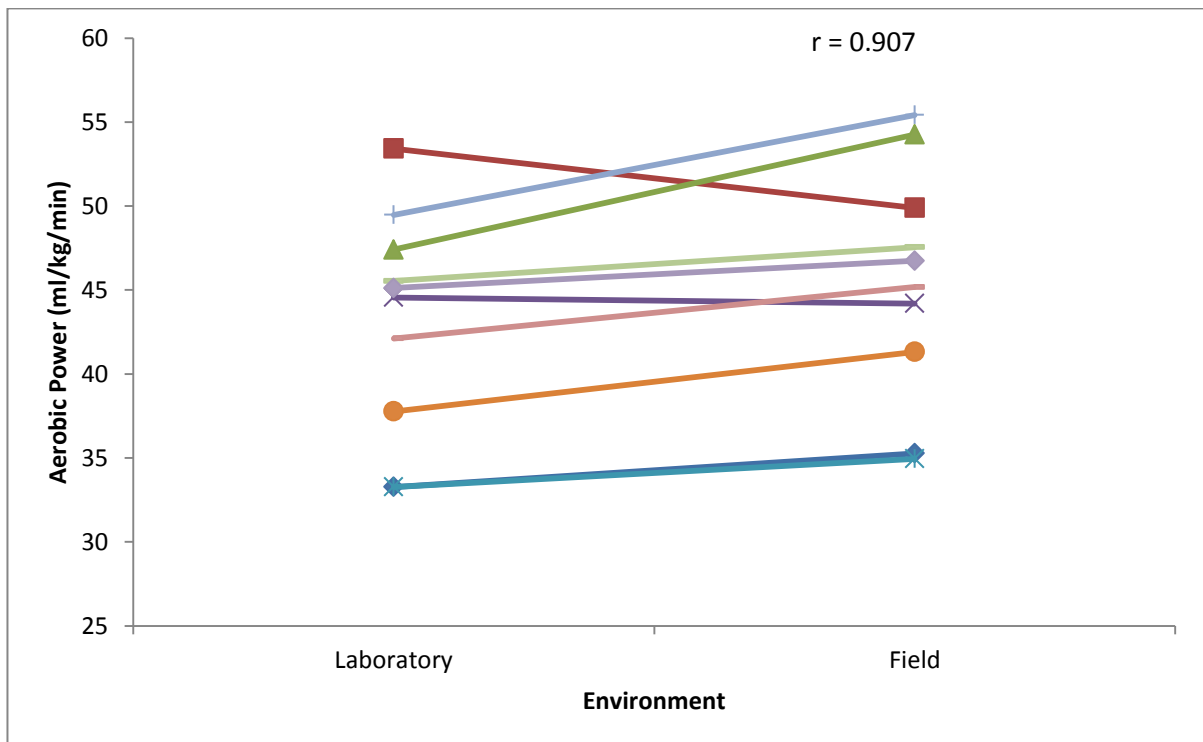


Figure 10: Laboratory and field based measurements of maximal aerobic power.

Discussion

The primary aim of this study was to measure the maximal aerobic power of elite SUP athletes with a traditional laboratory based method utilising a metabolic cart and compare the results to other water based athletes. The secondary aim of this study was to compare the laboratory based result to a field based result utilising a portable gas analysis unit. The aerobic power of elite SUP athletes has not previously been reported in the literature and the findings from this study provide some insight into the maximal aerobic fitness levels of elite SUP athletes.

The elite male athletes profiled in this study displayed high levels of maximal aerobic power as reported in other water sports which are upper limb dominant. For example, previous investigators have reported male surfer's maximal aerobic fitness ranging from 37.8ml/kg/min to 54.2ml/kg/min (Loveless & Minahan, 2010a; Meir et al., 1991), canoeists from 44.2ml/kg/min to 51.9ml/kg/min (Bunc & Heller, 1991; Hahn et al., 1988) and dragon boat racers from 42.3ml/kg/min to 50.2ml/kg/min. Although female surfers have been tested for maximal aerobic fitness whilst running on a treadmill (Schroeter, 2008) and cycling (Lowdon & Pateman, 1980) there is currently a minimal amount of normative data for upper limb specific $\dot{V}O_2$ max testing for female water based athletes. The maximal aerobic fitness of these female SUP athletes (36.61 ± 4.24 ml/kg/min) is similar to as yet unpublished data for elite female surfers we have tested on a swim bench ergometer of 34.30 ± 2.71 ml/kg/min (Furness, 2015).

The pooled data of both male and female values from the field based test demonstrated a high level of correlation between those results obtained from controlled laboratory based test. Given our results, it would appear that laboratory assessment of maximal aerobic power in elite SUP athletes is a valid alternative to field based testing. The tendency of the K4b2 portable unit to record consistently higher oxygen consumption than laboratory based metabolic carts has been reported previously (Duffield, 2004). The differences in the two environments as evident by the fixed bias error may be attributed to athlete comfort and familiarisation when in their natural SUP environment on water. The athletes reported they felt more comfortable completing the maximal aerobic power test whilst on the water, despite wearing the portable gas analysis device which weighed 800 grams (1.76lb) and required a utilization of a facemask to collect expired gasses for the duration of the test.

The differences in speed measures between the two environments are most likely attributed to the different methods for quantification of speed. The laboratory based speed measure is based upon measurement of the moment of inertia of the flywheel on the ergometer whereas the field based measurement was from the K4b2's integrated global positioning system (GPS). The GPS component of the K4b2 was only a 1Hz unit, which is a significantly lower frequency than the more modern, updated 15Hz units which are currently available. Previous research had reported quantification of speed via GPS is associated with measurement errors when sampling rates are low (Castellano et al., 2011). Field based measurement of speed with lower GPS sampling rates should therefore be interpreted with caution amongst this population. Our current research on field based assessment of speed in SUP utilized 15Hz GPS units, which identified an average speed of $2.72 \pm 0.2 \text{ m/s}$ during a marathon SUP event (~20km). Further research is therefore required to determine speed measurements across the water whilst SUP.

A limitation of this study is that two different protocols were used. Unfortunately, we were unable to instrument the SUP paddle to ascertain power outputs for the field assessment therefore a protocol was devised where an incremental increase in stroke rate was used. This was not feasible to replicate in the laboratory as once the subjects stroke rate reached 55 strokes per minute (and higher) athletes were unable to maintain normal strokes and consequently shortened their stroke length in an attempt to maintain the designated cadence. For example, the average stroke lengths found in this study were in excess of two meters per stroke and therefore a four meter stroke cycle must be completed in approximately one second if that protocol was used in the laboratory assessment, which is physiologically unrealistic.

Based upon our findings it would appear that elite SUP athletes have high maximal aerobic capacity which compares well to other water based athletes. Laboratory and field based measurements are highly correlated and can be used to assess SUP athletes provided the tendency for the field based measurements using the K4b2 unit to consistently measure higher values is noted.

Practical Applications

SUP is a new sport and recreational activity in which little scientific research exists. Our results demonstrate the aerobic capacity representative of elite level SUP athletes which can be used by sport scientists and coaches as targets. Elite level SUP athletes have aerobic capacities similar to other elite water based athletes highlighting that a high level of aerobic fitness is important for competitive SUP. This study demonstrates that SUP athletes can be assessed for maximal aerobic power in the laboratory with high correlation to field based measures.

4.2.3 Summary

The laboratory based investigation of the aerobic capacity of SUP athlete's shows high correlation to field based measures. Despite no comparative data specific to SUP, other water based sports which are upper limb dominant have reported measures of maximal aerobic capacity from which comparisons can be made. Incremental exercises testing on a specifically designed SUPergometer seems appropriate for testing of athletes in the laboratory and therefore will be utilised for investigation into the physiological profile of SUP participants in paper 3 – Profiling the sport of stand up paddle boarding on page 128.

4.2.4 Anaerobic Fitness Testing In Water Based Sports

The assessment of maximal paddling performance has been identified as being important for monitoring adaptation and improvements in performance due to training (Loveless & Minahan, 2010b). Anaerobic power has been assessed in a variety of athlete populations including surfing (205W-348W,(Loveless & Minahan, 2010b)), swimming (304W, (Hawley & Williams, 1991)), surf life saving (326W (Morton & Gaston, 1997))and kayaking (223W, (Fry & Morton, 1991)) as seen in Table 12.

Author	Subjects	Testing Mode	Power Output (W)
Hawley, 1991 (Hawley & Williams, 1991)	Competitive Swimmers	Arm Crank Ergometer	304
Fry, 1991(Fry & Morton, 1991)	State Kayakers	Kayak Ergometer	223
Morton & Gastin, 1997 (Morton & Gaston, 1997)	n = 7 (21 ± 1yrs) Surf Lifesavers	Swim Bench Ergometer	326 ± 29
Swaine, 2000 (Swaine, 2000)	n = 22 (23 ± 3.6yrs) Competitive Swimmers	Swim Bench Ergometer	304 ± 22
Loveless & Minahan, 2010 (Loveless & Minahan, 2010b)	n = 11 (17 ± 1yrs) Competitive Surfers	Swim Bench Ergometer	348 ± 23
Farley, 2011 (Farley et al., 2012)	n = 8 (20.4 ± 6.6yrs) National level Surfers	Modified Kayak Ergometer	205 ± 54.2

Table 12: Results from assessment of anaerobic power outputs. (Number of subjects and ages listed where reported).

In surfing, anaerobic power has been deemed to be important as it is thought to allow a greater speed on the water over short duration, enabling the athlete to catch more waves (Farley et al., 2011). Farley's study in 2012 reported a significant relationship between surfer's season ranking and anaerobic peak power output (Farley et al., 2012).

Prior research has identified that the upper body peak power output is highest amongst swimmers and surf lifesavers due to the specific demands of these sports (Loveless & Minahan, 2010b). Studies with swimmers have identified meaningful relationships between power output

measured with ergometers and swimming performance (Morton & Gaston, 1997; Rohrs, Mayhew, Arabas, & Shelton, 1990; Sharp, Troup, & Costill, 1982).

It would be assumed that anaerobic power assessed from a maximal anaerobic test would be more important for shorter duration SUP events, such as technical races and SUP surfing. Similar to the literature published in surfing, a SUP surfer could potentially catch more waves with higher power output, thus enabling the chance to score more points during an event. Summarising the findings from sports similar to SUP, it is assumed that the physiological profile of a SUP athlete would include high levels of aerobic fitness amongst a long distance racing SUP competitor, and that aerobic fitness could be predictive of performance unlike their surfing counterparts. Anaerobic fitness would appear to be important for catching waves like their surfing counterparts. The investigation of anaerobic fitness utilising an ergometer as done previously in water based sports will therefore be performed in Paper 3 – Profiling the sport of stand up paddle boarding on page 128.

4.2.5 Other Areas Profiled In Water Based Sports

Several previous studies have conducted investigations of the profiles of water sport athletes. Surfers have been found to have a shorter stature amongst its elite, as this may be more advantageous to performance. It has previously been reported that stability is inversely related to the height of the center of gravity above the base of support (Hayes, 1982). Mendez-Villaneuva showed that a shorter stature may be an advantage to surfing performance, as a lower centre of gravity would allow surfers to obtain better dynamic balance performance (Mendez-Villaneuva & Bishop, 2005). Conversely, successful rowers tend to be tall and lean (B. T. Smith & Hopkins, 2012).

A shorter stature may therefore also be beneficial to a paddle boarder's stability. Conversely a taller stature and greater reach could potentiate a greater arc of the blade in the water and therefore more power in each stroke leading to more speed. Many coaches believe that greater reach means greater speed on the water. Research into kayak paddling has found that reach should be limited to distances where high forces can be applied immediately (Kendal & Sanders, 1992). In canoeing, the most effective blade position has been found to be perpendicular to the water surface (Pelham & Holt, 1995a).

Previous biomechanical studies of the similar stroke performed in canoeing have examined the stroke frequency, stroke distance and stroke technique (Logan et al., 1980). It has been found that elite athletes have a higher stroke frequency, stroke speed and power in more advanced canoeists than amateurs (Hong & Johns, 2000). Throughout kayak racing, the average velocity is the average of the average velocities for each stroke (Michael et al., 2009).

Elite dragon boat paddlers were found to have increased muscular strength, enabling them to have better control of the paddle angle, resulting in greater efficiency. It was found that throughout the drive phase paddlers pulled the paddle back through the water via extension of the trunk, shoulder and by flexing the elbow (Ho et al., 2009). It is assumed that the SUP stroke would share many similarities to these other water based sports.

The previous research in similar water based sports may offer some insight into the ideal profile of the SUP athlete. Although SUP shares many similarities to surfing, canoeing and dragon boat racing, it is a unique sport which thus far has been minimally researched. The importance of fitness to performance in SUP has been demonstrated in the first study of this thesis, while the correlation of laboratory to field based measurement of aerobic fitness confirmed in paper 2. The physiological aspects, anthropometric measurements and biomechanical indices including stroke frequency, power and length in SUP will be assessed in the third study of this thesis with the data provided in this chapter utilised for comparison.

4.3 Training Utilising Unstable Surfaces, an Activity Similar To SUP

The fact that SUP is performed in a dynamic environment is possibly of benefit for the participant's postural control and stabilising musculature. It is proposed that paddle boarding requires the participants core musculature to be activated to stabilize while the muscles of the legs, arms, back and even feet and toes are being used to maintain balance on the varying stability aquatic environment (Hammer, 2011). Therefore there may be potential for key stabiliser muscle activation, improvements in balance and postural control. Postural control in standing has been found to be essential for the performance of sporting activities (Stambolieva, Diafas, Bachev, Christova, & Gatev, 2011) and proficiency in postural control may determine successful performance of athletic activities (Alderton, 2003). Effective postural control is reliant on sufficient muscle strength and endurance however (Alaranta, 1994).

As both the musculoskeletal system and postural control are of interest to this investigation, comparative data was sought. One training modality that has received a lot of attention is instability training. Despite minimal research on SUP, instability training shares many similar aspects to SUP and therefore the research behind it was explored to determine if musculoskeletal and balance attributes can be positively affected by its use.

Instability training has become a common place in many gyms and many rehabilitative and functional training programs incorporate a progression from isolation and education through to adding balance, increasing function, speed and rotation (Yoke & Kennedy, 2004). The use of unstable training environments has been purported in the popular literature to enhance sport-specific training effects through increased activation of stabilizers and trunk muscles (Anderson & Behm, 2004). A variety of devices including BOSU balls, physioballs and dura discs have been utilised with either body mass or external load as resistance to train the core musculature and increase balance ability (Behm, Drinkwater, Willardson, & Cowley, 2011). Some of these devices are pictured in Figure 11 below.



Figure 11: Instability training devices including (from the left) a dura disc, BOSU ball and a Swiss ball.

There is some evidence of an increase in core muscle activation when training on unstable surfaces in order to maintain control (Vera-Garcia, Grenier, & McGill, 2000). Due to the fact that it normally dictates using lighter weights and movement velocities, it is more suited for developing muscular endurance rather than muscle strength and power (Willardson, 2008). Instability training has been shown to elicit a greater signal amplitude via EMG in several key postural muscles, including the lumbo-sacral erector spinae (Behm & Anderson, 2005). Increases in core muscle activation of 47.3% have been recorded when training on unstable surfaces (D. Behm, A. Leonard, M. , W. Young, B. , W. Bonsey, A, C. , & S. MacKinnon, N., 2005a). It has been shown that unstable surface training also increases lower abdominal muscle activation (Behm et al., 2005a) and that strength adaptations are possible with instability training, provided that the degree of instability is moderate, not severe (Behm, Anderson, & Curnew, 2002). It has therefore been used extensively as a treatment for back pain (Behm, Willardson, & Cowley, 2011).

With back pain, it is thought the timing of the protective effects of the stability muscles is often delayed while the recruitment of other inappropriate muscles is early (Ferguson, Marras, Burr, Davis, & Gupta, 2004; P. W. Hodges & Richardson, 1996). It is thought that training on unstable surfaces could decrease the timing of co-contraction, allowing for rapid stiffening and therefore protection of the joints (Behm, Drinkwater, Willardson, & Cowley, 2010). It has been hypothesised that exercises that can improve the co-ordination and extent of core muscle activation could prevent and rehabilitate both low back pain and lower extremity injuries (Behm & Colado, 2012).

Another possible benefit of unstable resistance training would be the ability to achieve high muscle activation, as the muscles role is for both movement and stability (Anderson & Behm, 2004). This consequently leads to lower joint torques from the reduced loads, leading to less stress through the joint. It is thought that a moderately unstable training platform could prevent and recuperate both core and limb injuries and in cases of degeneration. Dynamic training on unstable surfaces is thought to restore and improve the sensory motor feedback arc, leading to the activation of efficient motor control strategies (Bullock Saxton, 2001; Laskowski, Newcomer-Aney, & Smith, 1997; Snyder-Mackler, 2001). It is thought that in the early stage of musculoskeletal injury, when force and power can be decreased due to the effects of inflammation, pain and stiffness, a balance program might be an ideal initial exercise to prevent the loss of force and power often associated with injury (Behm et al., 2002).

Studies have demonstrated that balance training may be more beneficial for less trained subjects (Gruber et al., 2007). It has been demonstrated that increases in rate of force development can be accomplished with balance training, without major strains of muscle. It was concluded from this study that this type of training could be beneficial to counteract the age related decline in the rate of force development and consequently the impaired balance control associated with this decline

It is thought that if individual's can improve their balance and stability, then strength and power may increase as well. Improvements in balance and proprioception from training on unstable surfaces can not only provide positive benefits for reducing falls but can also improve functional performance such as strength, power, running and other activities. Instability training has been shown to improve functional performance by 31%, and with the addition of a resistance training component, 105% improvement can be seen. (Behm, Willardson, et al., 2011)

Instability training can also benefit the lower limb. It is thought that the stabilising responsibility of the limb musculature when exposed to instability may more closely mimic the typical requirements of daily activities or sport (Anderson & Behm, 2004). Studies show that free weight squats exhibit greater muscle activation of the stabilisers of the trunk, knee and ankle when performing unstable resistance training when compared to stable exercise (Behm & Anderson, 2005; Schwanbeck, Chilibeck, & Binsted, 2009).

Utilising exercises on unstable surfaces has been shown to increase stabiliser muscle activity around the ankle (Behm & Anderson, 2005). Ferriera's study revealed a significant increase in muscle activity around the ankle on unstable surfaces compared to stable ground (Braun Ferreira et al., 2011). Proprioceptive exercises are performed on a daily basis in physiotherapy using unstable platforms in order to improve joint stability via an effect on the ligaments, joint capsule and musculature surrounding the joint (Braun Ferreira et al., 2011). Previous injury can damage ligaments and cause proprioceptive functional deficiency which can lead to chronic instability and further injury.

It is thought that the biggest contributor to proprioception around the ankle joint is the ligaments (Braun Ferreira et al., 2011). Training on unstable surfaces may generate rapid changes in the length of the ligament which stimulates afferent stimuli and reflexive motor responses in order to produce rapid joint stability (Myers, Riemann, Hwang, Fu, & Lephart, 2003). With unforeseen perturbation it is thought that the stabilization reflex of agonist-antagonist co-contraction is produced (Braun Ferreira et al., 2011).

Due to SUP closely resembling instability training, it is not unreasonable to make conclusions about its benefit for both trunk muscle endurance and postural control. The demonstrated benefits found from instability training for both muscular strength and endurance and postural control may also be found in stand up paddle boarding. Therefore, both the muscles utilised when paddling a SUP and the postural control of SUP participants requires investigation.

4.4 Musculoskeletal profiling in other activities and populations

To address the claims of SUP being of benefit to core strength and subsequently beneficial for back pain, an assessment of muscle activity during the activity is warranted. Previous research in other water based sports has also demonstrated that strength is importance to performance. The musculoskeletal profiles of SUP along with potential for benefit of SUP for strength for the general population will therefore be explored in this section.

The musculoskeletal system creates stable cross bridges that resist stretch and stores muscular energy (Myers et al., 2003). The importance of the peri-spinal muscles to provide support is demonstrated by the finding that the spine collapses under only 9kg of load when stripped of all muscle (Barr, Griggs, & Cadby, 2005). Intrinsic stiffness which is strongly influenced by muscular contraction provides the first line of defence for joint stability when force is applied to the joint (Myers et al., 2003). Deficits in the musculoskeletal system manifest in increased injury risk and therefore much of the previous research in this area is specifically about the pathological populations. There are specific muscles of importance around the trunk, pelvis, hip, knee and ankle which are important to both prevention of, and rehabilitation post injury.

It is thought that a strong 'core' facilitates force transmission between the lower and upper body (Cholewicki & McGill, 1996). A strong and stable lumbo-pelvic region ensures the efficient transfer of forces from the ground to produce movement or to generate torque at the extremities (Behm et al., 2005a). Several papers have found no performance increases when adding core strengthening exercises to athletic training regimens (Stanton, Reaburn, & Humphries, 2004; Tse, McManus, & Masters, 2005). This could be due to the ambiguity of what exactly constitutes core training and which particular muscle to target or by the confusion around the terms 'core strength' and 'core stability'. It could also be that core strengthening is more beneficial for injury prevention and rehabilitation than performance alone.

It is therefore necessary to differentiate between core strength and core stability. Core strength is required for athletic performance whereas core stability is usually reserved for rehabilitation (Gamble, 2007). Faries & Greenwood differentiated the two by suggesting that core stability refers to the ability to stabilise the spine as a result of muscles activity while core strength refers

to the ability of the musculature to then produce force through contractile forces and intra-abdominal pressure (Faries & Greenwood, 2007).

Kibler summarized core stability in the sporting environment as 'the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer and control of force and motion to the terminal segment in integrated athletic activities' (Kibler, Press, & Sciascia, 2006). Core stability has been defined as 'the product of motor control and muscle capacity of the lumbo-pelvic-hip complex' (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004), although Gamble points out that the term now describes any exercise that addresses some part of lumbopelvic stability (Gamble, 2007).

4.4.1 Assessment of muscle activity

An effective and efficient musculoskeletal system may be important for both performance and injury prevention. To determine the muscle activity while paddling a SUP, assessment and quantification of muscle activity is required. One such assessment is electromyography (EMG), the study of muscle electrical signals. The EMG signal is a measure of electrical currents generated in muscles when it is contracting which represents neuromuscular activity (Raez, Hussain, & Mohd-Yasin, 2006). Finding muscles which are used and which fatigue first in a specific sport is an important element of sport training planning, especially in individual sports (Gerzevic et al., 2011).

As EMG is a measure of muscle activation, it is assumed that movements that produce greater signal amplitude would produce greater strengthening benefits (Ayotte, Stetts, Keenan, & Greenway, 2007). It has been reported that muscle activation of greater than 60% MVC is required for strength benefits while an ideal level to build stability and endurance has been estimated at < 25% of an MVC (Vezina & Hubley-Koszey, 2000). Although previous research has confirmed activation of key muscles with SUP, magnitude of this activation, which gives insight into the potential training effect of the activity, has not.

There are several muscles around the trunk, hip, knee and ankle which are hypothesised to be active when utilising a SUP. These muscles have been studied previously in respect to spinal stability, joint stability and lower limb kinetic chain dynamics. They play an important role in

physiotherapists exercise based rehabilitation and dysfunctions of these muscles have been linked to pathological conditions. In order to determine the potential for SUP to be used as a rehabilitative tool, identification of key muscles targeted in rehabilitation is required. Some of these muscles were investigated in the EMG study found published in SUP (Ruess et al., 2013a), however their rationale for inclusion will be explored over the next section.

4.4.2 Muscles of significance around the trunk

Anecdotal reports of SUP being beneficial for people with back pain are due to its proposed effects of strengthening the muscles around the spine. Without the active input of muscles in the human body, instability occurs. It is thought that this instability is either a loss of control or excessive motion in the spinal segment's neutral zone, which can be caused by muscle weakness (Panjabi, 1992a). Muscle contractions create stable cross bridges that resist stretch and store muscular energy, ideally functioning to prevent this excessive movement and promote control (Myers et al., 2003) Intrinsic stiffness which is strongly influenced by muscular contraction provides the first line of defence for joint stability when force is applied to the joint (Myers et al., 2003).

It has been identified that a cause of back pain can be the instability of each individual lumbar segment (Danneels, Vanderstraeten, & Cambier, 2001). A key trunk muscle which has been assessed as being important for stability around the lumbar segments and therefore our investigation is the multifidus. It is reported that multifidus has both movement and stability roles, working with the other lumbar muscles to produce extension of the lumbar spine (Bogduk, Macintosh, & Pearcy, 1992). It also counterbalances the flexion force produced simultaneously in rotation by the obliques (Bogduk, 1997). The multifidus muscle has been shown to be important in provision of segmental stiffness, control of the spinal segments in the neutral zone, and for stabilising the spine when stability is challenged (Hides, Gilmore, Stanton, & Bohlscheid, 2008; Panjabi, 1992b).

Atrophy of the multifidus muscle is a common finding in studies after acute, chronic and discogenic back pain (Hides et al., 2008; Hides, Stokes, Saide, Jull, & Cooper, 1994). The recovery of this muscle is not automatic after short term resolution of back pain (Hides, Richardson, & Jull, 1996). The efficiency of the multifidus muscle has been previously shown to improve under

training loads around 30-40% of an MVC (Cholewicki & McGill, 1996), therefore avoiding the need for excessive loads. Rehabilitation of back pain specifically targeted at multifidus is evident in Daneels study in 2001 which attempted to change the cross sectional area of multifidus with a training intervention. In his study the only group which showed any significant change had a static and dynamic strengthening component with an added isometric phase being most crucial to the increase in cross sectional area (Danneels et al., 2001).

Several key core stabilisation exercises have been purported by rehabilitation experts to be more beneficial for increasing the of multifidus after back pain (Danneels et al., 2001). Core stabilisation exercises have also been identified as being important factor in minimizing the severity and frequency of mechanical back pain (Schellenberg et al., 2007). The effectiveness of core stabilisation programs on segmental hypermobility patients has been well documented (da Silva, Arsenault, Gravel, Larivière, & de Oliveira, 2005; Fritz, Whitman, & Childs, 2005; Hicks, Fritz, Delitto, & McGill, 2005).

It is therefore feasible in theory that SUP could be of benefit for training the multifidus muscle. Instability training with core resistance could potentially improve the function of both the active subsystem, being the spinal muscles, and the neural subsystem, being the control of these muscles by the central and peripheral nervous system. These are two out of the three interdependent subsystems required for spinal stability by Panjabi's model to explain the development of spinal pain (Panjabi, 1992a).

In conjunction with the multifidus muscle, the oblique muscles, erector spinae and rectus abdominis were also investigated in the EMG paper on SUP (Ruess et al., 2013a). There has been discussion in the literature about whether to strengthen the flexors of the trunk, the extensors, neither or both to gain core stability (Reid, Hazard, & Fenwick, 1991). The theoretical rationale for strengthening the flexors was a hypothesised decompression of nerve roots, stabilisation of the spine and increased intra-abdominal pressure (Reid et al., 1991). It is thought this stabilisation of the spine would decrease load on the spine and discs.

The rectus abdominis acts to flex the vertebral column and forms part of the anterior abdominal wall (Moore, 2011). The rectus abdominis is connected to the obliques via an aponeurosis which also form part of the anterior abdominal wall. The obliques are primarily involved in rotation with the ipsilateral external oblique is connected to the contralateral internal oblique, working

together to produce torsional movement of the trunk, working cyclically in rotational movements such as in gait. It is also thought that co-contraction of the obliques increases axial trunk stiffness (Lee, Hoozemans, & van Dieën, 2010)

The erector spinae group is the largest muscular mass of the back and includes the spinalis, longissimus and iliocostalis ("Gray's anatomy," 2012). It forms part of the group of extensors along with the previously mentioned multifidus muscle. The primary role of the back extensors is that of a postural muscle, to maintain the upright standing posture and to control forward bending eccentrically (Adedoyin, Mbada, Farotimi, Johnson, & Emechete, 2011). Weakness in extensor strength is evident in cases of back pain (Adedoyin et al., 2011) and strength training of the extensors has proven to be effective treatment in musculoskeletal disorders (Kollmitzer, Ebenbichler, Sabo, Kerschman, & Bochsansky, 2000).

Although these muscles have been highlighted in isolation, it should be noted that the muscles all form what has been called a flexible myofascial axial ring running from the thorax to the pelvis, due to their connections (Vleeming, Schuenke, Danneels, & Willard, 2014). This ring is described as running from transversus abdominis to the internal obliques, through the tendon of the rectus abdominus and into the middle layer of the thoracolumbar fascia. Posteriorly, the superficial layer of the thoracolumbar fascia connects the lumbar erectors and the multifidus. Recently the internal oblique has been shown to contract in conjunction with the transverse abdominis with in more unstable postures (Ainscough-Potts, Morrissey, & Critchley, 2006), a significant finding considering the attention transverse abdominis has received in regards to rehabilitation (P. W. Hodges & Richardson, 1996) and the difficulty in gathering recording from such a deep muscle with surface EMG. This overall, synergistic action between the back extensors and abdominal wall muscles has been confirmed via EMG during unilateral transfer tasks (Hubley-Kozey, Butler, & Kozey, 2012).

Due to the description of SUP being associated with both isometric trunk contraction and rotation, it is assumed that all the aforementioned muscles would show appreciable levels of activity to complete the task. The rectus abdominis, internal and external obliques, multifidus and the erector spinae groups are important in both stability of the trunk and motion around it and therefore have been included in the EMG analysis found in Pilot Study 1 – An electromyographic analysis of Stand Up Paddle Boarding on page 104.

4.4.3 Muscles of significance in the lower limb

It is important to note that the lower extremity functions as a kinetic chain (Boren et al., 2011). The closed kinetic chain theory suggests that proximal strength is needed for the control of the distal segments to prevent injury (Niemuth, Johnson, Myers, & Thieman, 2005). An example of this is found where excessive pronation due to hip weakness can lead to Achilles tendinopathies (McCrory, Martin, & Lowery, 1999). Many rehabilitative programs of dysfunctions of the lower limb aim to strengthen the lower extremity without exacerbating pain via functional rehabilitation exercises using closed kinetic chain activities (Doucette & Child, 1996; Hung & Gross, 1999). Programs of this nature have shown early success for improving faulty movement patterns, increasing strength and reducing injury rates (Distefano, Blackburn, Marshall, & Padua, 2009).

Weak proximal muscles around the pelvis can therefore exhibit effects on more distal segments (Leetun et al., 2004). Some authors believe that numerous pathologies can arise from the inability to maintain correct alignment of the pelvis on the femur such as tibial stress fractures, low back pain, ITB syndrome, ACL injury and patellofemoral pain syndromes (Boren et al., 2011). Numerous rehabilitation exercises specifically revolve around strengthening the gluteal muscles because of their role in maintaining a level pelvis and preventing adduction and internal rotation during single leg stance (Leetun et al., 2004).

Of the muscles of the lower limb, the gluteus maximus and medius contribute most significantly to postural and functional abilities such as gait (Ayotte et al., 2007) and have also been included into our investigation. Weakness of the gluteus medius and maximus can contribute to lower extremity injury by changing joint loading patterns and control (Distefano, Blackburn, et al., 2009). The gluteus medius concentrically abducts the hip, isometrically stabilises the pelvis and eccentrically controls both hip adduction and internal rotation (Distefano, Blackburn, et al., 2009; Moore, Dalley, & Agur, 2006). In weight bearing the gluteus medius controls the pelvis and femur in the frontal plane and is often the target of rehabilitative efforts to stabilize the pelvis and decrease valgus alignment at the knee (Ayotte et al., 2007). Weight bearing exercises have shown on average to generate greater EMG signal amplitude than non-weight bearing exercises (Bolgla & Uhl, 2005).

The major functions of the gluteus maximus include stabilising the lumbo-pelvic region, eccentric control of hip flexion and concentric control of hip extension (Moore et al., 2006). Preece found that greater gluteus maximus activity resulted in larger external torque applied to the femur which rapidly slowed the tibial rotation in gait (Preece et al., 2008). It is thought that gluteus maximus contributes to joint stability at the sacro-iliac joint through force closure due to its fibres running perpendicularly to the joint surface (Hossain & Nokes, 2005).

It can be postulated that low back pain can alter gluteal function due to the proximity of both the superior gluteal nerve and sinuvertebral nerve to the lumbar segments often afflicted with pathology in low back pain cases (N. Smith, 1999). It is known that reflex inhibition due to pain can occur well away from the affected segment. Equally, weakness of the gluteal muscles can lead the low back susceptible to excess rotational forces, it's most vulnerable plane of movement (N. Smith, 1999). Gluteal weakness may be evident in cases of low back pain; however it could be either a consequence or cause.

Further down the kinetic chain, the knee joint is the largest and most complex joint in the human body (M. D. Miller & Thompson, 2015) and strengthening of the quadriceps muscle group is an important rehabilitative exercise which is commonly prescribed post-surgery. Of the quadriceps group, the vastus medialis obliquus (VMO) and vastus lateralis (VL) have received the most attention with respect to rehabilitation.

Under ideal circumstances VMO is able to counterbalance the larger VL is then considered a medial stabiliser of the knee joint (Pattyn et al., 2011). Argument exists about these muscles in regards to optimum strength ratios, whether isolated VMO training exists and whether or not the timing of VMO is delayed in pathological conditions such as patellofemoral pain syndrome (PFPS). Some authors have supported the concept of delay of VMO to VL for a reason for PFPS (Boling, Bolgla, Mattacola, Uhl, & Hosey, 2006) whereas some authors have found no delay in timing of the VMO (Karst & Willet, 1995; Owings & Grabiner, 2002; C. Powers, M. , Chen, Reischl, & Perry, 1996). Other authors argue that a demonstrable deficit in problematic knees is the magnitude of force elicited from the VMO. Some argue that the problem lies with strength alone and that a higher degree of VL recruitment relative to VMO exists with static and dynamic exercises in pathological knees (J. Miller, Sedory, & Croce, 1997) while others claim that it is simply a weakness of all the quadricep muscles (C. Powers, M. Chen, P, Y. Reischl, S, F. Perry, J, 1996).

The idea of the entire quadricep group being at fault has received support with confirmation via Magnetic Resonance Imaging (MRI) of decreased cross sectional area of this muscle problematic knees when compared to healthy controls (Pattyn et al., 2011) EMG analysis of normal subjects has shown that the VMO/VL ratio should be about 1:1 (Qi & Ng, 2007). Physiotherapy programs designed to increase the activity of VMO relative to VL have become integral for patients suffering the effects of PFPS (Qi & Ng, 2007) and often involve weight bearing exercises.

Instability training for knees specifically has shown that greater vastus medialis and vastus lateralis signals are evident via EMG when performing free squats when compared to a smith machine squat (Schwanbeck et al., 2009). Studies show that six weeks of weight bearing rehabilitation improved the timing of VMO relative to VL (Boling et al., 2006). Whole body vibration was found to elicit higher EMG activity and the greater the amplitude and frequency, the greater the effect (Krol et al., 2011). It is therefore assumed that the more unstable the surface is, or the more perturbation the body faces, the higher the EMG signal from VMO & VL.

It is thought that factors below the knee can also play a role in the kinematics around the knee and hip joint. Numerous authors have explored the effect of excessive or prolonged pronation at the foot (C. Powers, M. , Chen, Reischl, & Perry, 2002; Reischl, Powers, Rao, & Perry, 1999; Tiberio, 1987). Using the screw-home mechanism around the tibiofemoral joint, these authors report that the tibia must be externally rotated relative to the femur so that full extension can be achieved during midstance and terminal stance of gait. It is thought that excessive pronation can lead to the tibia remaining internally rotated, causing the femur to rotate internally excessively in order to complete this mechanism and obtain extension during these two phases of the gait cycle (Ireland, Willson, Ballantyne, & Davis, 2003).

Although local muscles at the knee joint can be responsible for pathology, the effects of the muscles proximal and distal in the kinetic chain need to be examined. Foot mechanics can influence the kinetic chain from a proximal to distal route. Excessive pronation at the foot can be problematic for the foot, the knee, the hip and the low back (Rothbart, Hansen, Liley, & Yerratt, 1995; Scattone Silva, Maciel, & Serrão, 2015). The intrinsic foot muscles are thought to control the excessive pronation which has been linked to several overuse injuries including plantar fasciitis, hallux valgus, Achilles tendonopathies, tibialis posterior dysfunction and patellofemoral pain syndromes (Jung et al., 2011).

The foot position naturally adopted on a SUP is similar to the short foot described by Janda and VaVrova in 1996 in which the medial and longitudinal arches are elevated to improve the foot's biomechanical position away from a pronated position (Janda, 1996; C. Powers, M. et al., 2002). It has been hypothesised that this technique enhances the cutaneous distribution on the plantar surface of the foot by increasing pressure in the areas still in contact with the ground when elevating the longitudinal arch (DeStefano & Greenman, 2011). This alignment of the foot could hypothetically prevent the compensatory internal rotation of the lower limb from a distal to proximal route (Tiberio, 1987).

Research on the ankle has focussed on the major stabilisers of the ankle including the gastrocnemius, soleus, tibialis anterior and posterior and the peroneals. Ferriera's study examined the tibialis posterior, tibialis anterior, peroneus longus and both heads of the gastrocnemius, deeming these muscles to be most important for monopodal support. He found that unstable surfaces were fundamental to the sensory-motor rehabilitation of the ankle joint, demonstrating that these muscles showed much greater activity under unstable conditions (Braun Ferreira et al., 2011). The importance of this is also relevant to the elderly population as research revolving around falls has shown that the capacity of muscles to develop force rapidly diminishes with age, especially the foot and leg extensors.

There are key muscles around the trunk, pelvis, knee and ankle which are important for stability and segmental control, both locally and on some occasions more distally. These muscles have been studied previously and appear to be more highly activated under conditions of instability. A review of published papers utilising EMG for investigation of muscle activity on unstable surfaces was performed.

4.5 A review of Electromyography and unstable surfaces from the scientific literature

Few articles have been published examining EMG analysis of unstable conditions. Inclusion criteria required the subjects to be in standing in bilateral stance under conditions of varying stability. Despite many articles in the literature performing exercises in single leg stance, these conditions were not deemed relevant to SUP. In total, six articles met the criteria for the literature review and can be found in Table 13.

Three articles have examined the effects of performing a squat on unstable surfaces (Behm & Anderson, 2005; McBride, Cormie, & Deane, 2006; Wahl & Behm, 2008). McBride examined isometric squats and found a decrease in force output but also significantly less VMO and VL activity in the unstable condition when compared to the stable condition (McBride et al., 2006). He found no increase in synergistic or antagonistic muscle activity measured by EMG. No significant differences were found between the two surfaces when examining the other two muscles, biceps femoris and the medial head of the gastrocnemius.

Anderson and Behm also examined the squat under varying stability, utilizing smith machine squats, free squats and squats standing on an inflatable disc under each foot (Behm & Anderson, 2005). Key findings were that the activity of the upper lumbar erector spinae, lumbosacral erector spinae, abdominal stabilisers and soleus were significantly higher under the unstable condition. Similar to McBrides results, there was minimal change in the biceps femoris and vastus lateralis in the different conditions.

In contradiction to these papers, Schwanbeck showed that greater vasus medialis and vastus lateralis signals were evident via EMG when performing a free squat when compared to a smith machine squat (Schwanbeck et al., 2009). Despite not using an unstable surface per se, he rationalised that the free squat was a condition of greater instability than the smith machine squat.

Wahl and Behm examined EMG activity of key muscles around the lower limb in highly resistance trained individuals under a variety of conditions (Wahl & Behm, 2008). Muscles measured included soleus, biceps femoris, rectus femoris, lower abdominals and lumbosacral erector

spinae. All muscles increased activity when standing on a Swiss ball, and all but rectus femoris when standing on a wobble board. The BOSU ball condition elicited no increase in any muscle activity and a dyna disc, none but the lumbosacral erector spinae. The authors concluded that moderate instability did not provide a sufficient challenge to highly resistance trained individuals.

The gluteus medius was specifically targeted in an EMG study of five different weight bearing conditions (Krause et al., 2009). It was found that unilateral conditions displayed a statistically significant increase in gluteus medius activity as compared to bilateral stance. In addition, it was found a greater increase in EMG activity could be elicited with an Airex cushion.

One study examined the muscles around the knee and ankle with varying levels of instability. The muscles examined were the rectus femoris, biceps femoris, tibialis anterior and gastrocnemius (Barbado Murillo, Sabido Solana, Vera-Garcia, Gusi Fuertes, & Moreno, 2012). It was found that as the degree of instability increased, so did the muscle activity. It was hypothesised that flexor co-activation of the flexor/extensor group was evident of an attempt to increase joint stability of both the knee and ankle.

A study on the ankle specifically examined the tibialis posterior, tibialis anterior, peroneus longus and both heads of the gastrocnemius (Braun Ferreira et al., 2011). Unstable surfaces were found to be fundamental to the sensory-motor rehabilitation of the ankle joint, demonstrating that these muscles showed significantly greater EMG activity under unstable conditions (Braun Ferreira et al., 2011).

Articles have demonstrated that despite overall muscle force output decreasing, this is often not reflective of increasing EMG activity of the synergist and antagonist muscles (Anderson & Behm, 2005). An example of this is evident in Behm's study of a dynamic leg extension in which despite force output decreasing in magnitude of 20.2%, synergistic muscle activity increased by 30.3% and antagonistic muscle activity by 29.1% (Behm et al., 2002). It was assumed that this extra muscle activity was primarily involved in providing joint stability.

Conversely, another study found no increase in synergistic or antagonistic muscle activity despite an overall decrease in force output when examining the upper limb during an unstable exercise (Anderson & Behm, 2004). Despite these two studies not performed in weight bearing conditions, the decrease in force output is also seen in weight bearing activities (McBride et al., 2006).

Author, Year	Conditions	Muscles Investigated	Findings	Conclusion
Anderson & Behm, 2005	Squatting in varying levels of instability (smith machine, free squat, standing on balance discs.	Soleus, vastus lateralis, biceps femoris, abdominal stabilisers, upper lumbar erector spinae, lumbo-sacral erector spinae	Increase in soleus, abdominal stabilisers, upper lumbar erector spinae, lumbosacral erector spinae in unstable condition.	Performing squats on an unstable surface may permit a training effect on the trunk muscles responsible for stabilising the spine.
McBride, 2006	Isometric Squat on stable vs unstable (standing on inflatable balls)	Vastus lateralis, vastus medialis, biceps femoris, gastrocnemius (medial head)	Decrease in vastus lateralis & vastus medialis in unstable condition.	Unstable isometric squatting does not result in a significant increase in muscle activity.
Wahl & Behm, 2008	Highly Trained individuals standing & performing exercises on devices with varying levels of instability. (DynaDisc, BOSU ball, wobble board, swiss ball).	Soleus, biceps femoris, rectus femoris, lower abdominals, lumbosacral erector spinae	Increased muscle activity in all muscles when standing on a Swiss ball and all muscles except rectus femoris when standing on a wobble board. Increase in soleus and lower abdominals when squatting on Swiss ball and wobble board. No increase in muscle activity while exercising on a dyna disc.	Moderate instability did not provide sufficient challenges to highly trained individuals possibly due to enhanced stability obtained from the use of free weights. A greater degree of instability is recommended for highly trained individuals.
Schwanbeck, 2009	Free weight squat (unstable) vs smith machine squat (stable)	Tibialis anterior, gastrocnemius, vastus medialis, vastus lateralis, biceps femoris, lumbar erector spinae & rectus abdominus.	Gastrocnemius, biceps femoris & vastus medialis all significantly higher EMG signal during unstable condition. EMG signal averaged over all muscles 43% higher in unstable vs stable.	Free weight exercises may be more beneficial for people who are looking to strengthen plantar flexors, knee flexors and knee extensors.
Ferreira, 2011	Standing on stable and unstable surfaces with eyes open and eyes closed. (stable ground, trampoline, balance platform, proprioceptive disc, proprioceptive platform)	Tibialis posterior, tibialis anterior, peroneus longus and gastrocnemius.	Significant increase in muscle activity in all conditions except the trampoline. Greater increases with the eyes closed.	Unstable surfaces elicit significant increases in muscles around the ankle.
Murillo, 2012	Standing on a stability platform under stable, medium instability and high instability conditions	Gastrocnemius, tibialis anterior, rectus femoris and biceps femoris.	Increases in EMG activity of all muscles as the instability increased.	Increases in joint stability from co-contraction of flexors/extensors with increasing levels of instability.

Table 13: Articles examining muscle activity via EMG on unstable surfaces

The use of unstable surface training to elicit muscular strength and endurance gains is a previously researched occurrence. Clearly there are muscles of importance through the lower limb which are essential to providing support and stability around the hip, knee and foot. The use of a paddle board to provide sufficient instability as a training platform could theoretically provide the stimulus to maintain or increase strength and endurance around these key muscles. In addition, instability training via this modality could also provide a challenge to increase proprioception and strength post injury as part of a rehabilitation regime. To further investigate these theoretical benefits, an EMG study of the previously mentioned muscles was developed.

PILOT STUDY 1

AN ELECTROMYOGRAPHIC ANALYSIS OF STAND UP PADDLE BOARDING

Schram, B., Hing, W., Climstein, M. (2014) An electromyographic analysis of stand up paddle boarding. *Pilot Study of methodological design – not submitted to a scientific journal.*

Introduction

Stand up paddle boarding (SUP) is a relatively new sport and recreational activity which is increasing in popularity around the world due to its proposed fitness and core strength benefits (Hammer, 2011). SUP is widely described as the fastest growing sport in the world. SUP is a hybrid of surfing and paddling in which participants can either distance paddle and/or surf waves (Walker et al., 2010). Many websites anecdotally advocate the use of SUP to increase strength, core stability and decrease back pain. However, a recent review of the literature found no scientific evidence to substantiate the proposed benefits.

Due to the fact that SUP is performed in a dynamic environment, it is assumed that key postural muscles around the ankle, knee, hip and trunk would be utilised during this activity. The use of unstable surface training to elicit muscular strength and endurance gains is a previously researched and demonstrated occurrence (Behm & Anderson, 2005; McBride et al., 2006; Wahl & Behm, 2008). To infer the forces around a joint and through a muscle, the measurement of co-contraction and muscle activation is often utilized (Knarr, Zeni, & Higginson, 2012). Along with endurance testing of specific muscles, electromyography (EMG) can be used.

EMG is the study of muscle electrical signals. The EMG signal is a measure of electrical currents generated in muscles when it is contracting which represents neuromuscular activity (Raez et al., 2006). Finding muscles which are used and which fatigue first in a specific sport is an important element of sport training planning, especially in individual sports (Gerzevic et al., 2011).

As EMG is a measure of muscle activation, it is assumed that movements that produce greater signal amplitude would produce greater strengthening benefits (Ayotte et al., 2007). Research suggests that an activation of >60% MVC is required for strength benefits, whereas the ideal level to build stability and endurance has been estimated at < 25% of an MVC (Vezina & Hubley-Koszev, 2000).

Many rehabilitative programs of dysfunctions of the lower limb aim is to strengthen the lower extremity without exacerbating pain via functional rehabilitation exercises using closed kinetic chain activities (Doucette & Child, 1996; Hung & Gross, 1999). Programs of this nature have shown early success for improving faulty movement patterns, increasing strength and reducing injury rates (Distefano, Blackburn, et al., 2009).

Clearly there are muscles of importance through the lower limb which are essential to providing support and stability around the foot, knee, hip and trunk. It is proposed that the use of a paddle board to provide sufficient instability as a training platform could theoretically provide the stimulus to maintain or increase strength and endurance around these key muscles. In addition, instability training via this modality could also provide a challenge to increase proprioception and strength post injury as part of a rehabilitation regime.

Methods

A total of 7 people were recruited from a student population. There were varying levels of experience amongst the participants, with one an experienced paddler, two being novice paddlers and the other four having never paddled. Participants were free of lower limb musculoskeletal injury or any history of back pain. The study was approved by the University Human Research Ethics Committee and each participant formally consented prior to taking part in the study.

An EMG system (Mega WBA EMG, Finland) with a 1000 Hz sampling rate and 10-500Hz band pass filter was used to determine muscle activation in the 5 different conditions. Electrode placement and normalisation was as per SENIAM guidelines and signals were normalised with the use of maximal voluntary contractions which the participants performed 3 times to ensure the maximum was reached. Participants were instructed to elicit a contraction over 3 seconds to maximum, hold the maximum for 3 seconds and then slowly release the contraction over another 3 seconds. Several key muscles around the trunk, hips, knee and ankle were prepared by shaving the skin and cleaning with alcohol. These muscles included the peroneus longus (PL), vastus medialis obliquus (VMO), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), gluteus medius (GMed), gluteus maximus (GMax), external oblique (Eo), rectus abdominus (RA), the lumbar erectors (ES) and multifidus (MF). Muscle activation was measured in five different scenarios including standing, paddling at 5W on the left and right side on a SUP ergometer (Kayakpro) and maximal exertion paddling on the right and left. The EMG signal was used to evaluate the extent of muscular demand for key postural muscles around the foot, knee, hip and trunk.

Statistical Analysis

Statistical analyses included repeated measures analysis of variance (ANOVA) to determine differences between the different conditions. Tests for sphericity were performed and when violated, appropriate adjustments were made. The results were analysed for differences in left to right paddling for left and right muscle activation but also pooled to determine differences in standing muscle activation to activation at low and high intensity. All statistical tests were performed utilising the Statistical Package for the Social Sciences (SPSS, Version 22).

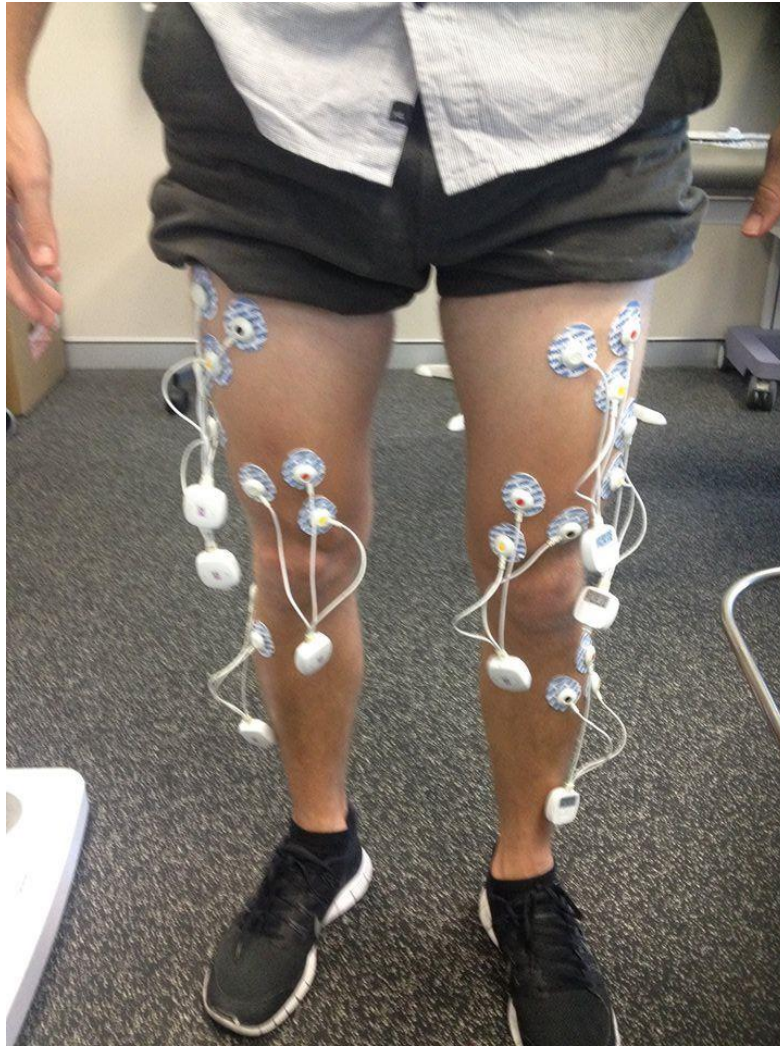


Figure 12: sEMG placement for the lower limb as per SENIAM guidelines.

Results

Muscle intensity changes with increasing instability

Figure 13 illustrates increases in muscle activity of the muscles of the trunk including the rectus abdominus, external obliques, multifidus and erector spinae with increasing intensity. The average percentage of MVC of muscles around the hip knee and ankle also were seen to increase including in the gluteus maximus, gluteus medius, rectus femoris, vastus medialis obliquus, vastus lateralis and peroneals.

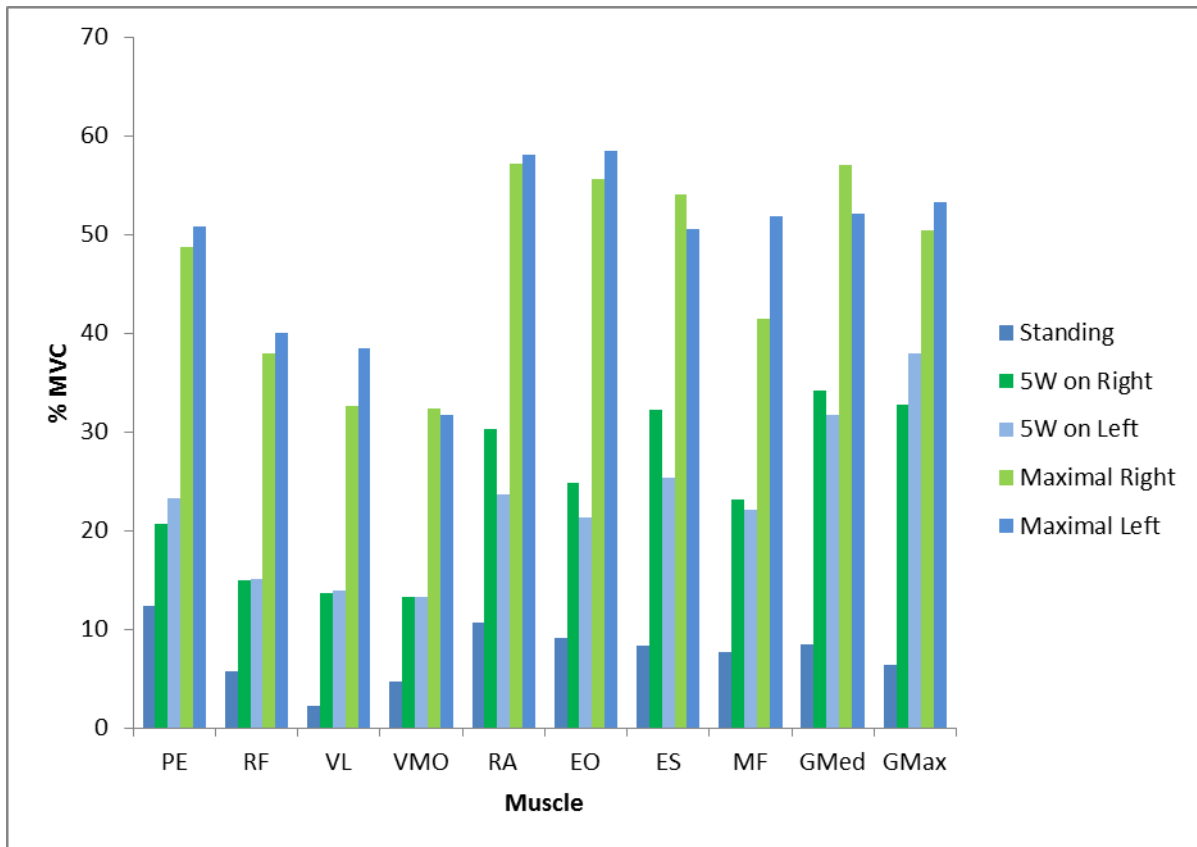


Figure 13: Average MVC's of selected muscles through the varying levels of difficulty.

Ipsilateral and Contralateral differences

Results demonstrated variable muscle activation during the activity. In the standing condition, there were no significant differences between right and left sided muscle activity except in the rectus femoris and erector spinae. When paddling at 5Watts on the right, there was significantly ($p < 0.05$) greater muscle activity in the left peroneal (+39.21%), there were no other significant differences between contralateral muscles. Whilst paddling at 5 W on the left, there was significantly ($p < 0.05$) greater muscle activity on the left peroneal (+64.06%), rectus femoris (+84.67%) and erector spinae (+113.51%) activity when compared to the right, and significantly more right external oblique activity than the left (+56.31%). When paddling maximally on the right, the right rectus femoris (+242.68%) and VMO (+93.39%) were significantly ($p < 0.05$) greater than the left. When paddling maximally on the left, the muscle activity of RF (+166.35%), VL (+76.53%), VMO (+69.53%) and ES (+136.22%) on the left were significantly greater than the right. There were no significant differences with Gmed or Gmax with respect to side.

Muscles as a group

When the intensity data was pooled to compare low intensity and high intensity, the peroneal's did not increase muscle activity significantly when moving from standing to paddling at 5W but did increase when paddling at high intensity. The RF, VL, VMO muscles of the lower limb and the RA, EO, ES and MF of the trunk increased in intensity from standing to low intensity and to high intensity. The Gmed and Gmax both significantly increased while paddling at 5W but not significantly from 5W to maximal paddling.

Muscle	Standing	5W on Right	5W on Left	Maximal Right	Maximal Left
PE	12.32 (7.37)	20.62 (16.68)	23.33 (23.63)	48.74 (28.57)	50.79 (37.45)
RF	5.70 (4.61)	14.92 (14.88)	15.05 (8.61)	37.96 (28.51)	40.01 (24.88)
VL	2.23 (1.19)	13.64 (6.07)	13.92 (8.20)	32.66 (11.35)	38.47 (19.61)
VMO	4.69 (3.43)	13.30 (5.67)	13.23 (8.36)	32.42 (16.31)	31.73 (12.38)
RA	10.63 (7.78)	30.31 (15.43)	23.64 (12.51)	57.11 (28.19)	58.03 (25.29)
Eo	9.06 (7.96)	24.85 (16.02)	21.33 (14.39)	55.60 (28.95)	58.46 (31.95)
ES	8.34 (4.58)	32.25 (24.88)	25.41 (16.54)	53.99 (29.28)	50.55 (30.47)
MF	7.68 (3.46)	23.14 (11.66)	22.07 (9.19)	41.47 (25.05)	51.79 (26.22)
GMed	8.50 (2.85)	34.13 (13.87)	31.73 (19.14)	57.07 (15.75)	52.12 (14.36)
GMax	6.33 (3.25)	32.80 (15.97)	37.93 (11.42)	50.4 (26.99)	53.31 (24.94)

Table 14: Average %MVC of muscles under increasing intensity. Mean (\pm SD).

Discussion

The aim of this pilot study was to determine the degree of activation of muscle activity that is deemed important to trunk and lower limb stability whilst paddling a SUP. This study was exposed to methodological issues including obtaining a high enough MVC in many of the trunk muscle tests. Signal drop out and signal noise was occasionally observed when the paddle or arm passed in proximity to the surface electrodes.

The increasing levels of instability seemed to display an increase in muscle activation measured by EMG. This finding has been found previously where instability training has shown to elicit a greater signal amplitude via electromyography (EMG) in several key postural muscles (including the lumbo-sacral erector spinae) (Behm & Anderson, 2005). In addition there appears to be some

evidence of contralateral trunk muscles activating with unilateral paddling. Previous research has found that unilateral exercises such as a single arm press will cause greater activation of the contralateral trunk stabilisers (Behm et al., 2005a).

The muscle activation of the trunk muscles at low intensity in this study compare well to an EMG study on several rehabilitation exercises including the front bridge, back bridge, side bridge and bird dog exercise (García-Vaquero, Moreside, Brontons-Gil, Peco-González, & Vera-Garcia, 2012). In this study the RA was activated most in the prone bridge exercise (29.5 ± 28.6 right, 27.6 ± 15.4 left), the EO muscles with the side bridge with hip extension (27.7 ± 15.5 right, 30.8 ± 18.2 left) and the ES muscles with the back and side bridge (22.7 ± 12.8 right, 18.5 ± 7.9 left). The efficiency of the multifidus muscle has been previously shown to improve under training loads around 30-40% of an MVC (Cholewicki & McGill, 1996), similar to the numbers found during higher intensity paddling in this study. Given that these exercises are frequently given as part of spinal stabilisation rehabilitation regimens, perhaps SUP could be utilised in a similar manner at low intensity to provide a similar strengthening effect of the perispinal muscles.

The gluteals did not display any significant difference in muscle activity on one side compared to the other when alternating from a left to a right side paddle. This may demonstrate a bilateral, stabilising effect on the pelvis while preventing excessive rotation through the hips (Ayotte et al., 2007). This finding is in agreement with Ruess, who after breaking down the paddle stroke found equal activation through the lower limb during the catch phase which they hypothesised to primarily involved in stabilising due to the unstable environment while the majority of the power is produced in the upper limb (Ruess et al., 2013a). Effective force transfer through the core and the control of excessive rotation through the pelvis and hips may be crucial both power development and injury prevention in SUP. The trunk musculature may be required to form a kinetic chain to drive power development from paddle to board during the activity.

The activity of the muscles around the knee in this study including rectus femoris, vastus medialis and vastus lateralis also increased as instability increased. This finding is in agreement with Schwanbeck who found increase in VMO activity with a free weight squat when compared to a smith machine squat (Schwanbeck et al., 2009). In their study VMO was active 49% more under the more unstable condition, similar to the 41.92% increase in moving from 5W low intensity paddling to maximal paddling in this study. The increase in muscle activity from rectus femoris with greater amounts of instability has been found previously (Barbado Murillo et al., 2012). The

increasing muscle activity of the peroneals in this study are in agreement with Ferriera's study which demonstrated an increase in muscle activity with greater instability (Braun Ferreira et al., 2011).

There was a high level of variability in percentage of activation and standard deviations of muscles relative to a maximal voluntary contraction which was hypothesised to reflect the varying skill levels of the small number of participants of the study. The original intention was to compare the SUP ergometer EMG recordings to a field based measurement of the same muscles on a paddle board in the water. Unfortunately this aspect of the study was plagued with methodological issues including signal drop out and the concern of equipment getting wet. Due to these issues, this study was deemed to be a pilot study for this thesis, however part of the methodological process. Further study utilising EMG and SUP is ongoing to ascertain the intensity of muscle activation to be able to make clear statements of muscle activation while utilising a SUP.

Summary

- Greater intensity and therefore greater instability elicits greater muscle activity in muscles of the lower and limb.
- Paddling on one side seems to elicit greater lower limb muscle activation on the contralateral leg with bilateral activation of the trunk muscles regardless of side.
- Muscles of the lower limb and trunk are activated during SUP at low intensity to a similar amount as many rehabilitation exercises, highlighting a potential for SUP to be used as a rehabilitative device.
- It appears as though the trunk musculature provide stabilising contractions to form a solid base for power development through the upper limb as a kinetic chain through the paddle.

4.6 Endurance Testing of Trunk Musculature as an Alternative Measure of Muscular Involvement

Due to the methodological issues with investigation of the musculature involved in SUP alternative means of investigation muscular benefits of SUP were explored. Due to the evidence of the trunk musculature providing bilateral stabilising contractions to provide a base from which movement occurs, it was highlighted as an important link in the kinetic chain. To assess the effects of SUP on core muscles, endurance testing is a way of inferring the properties of these key muscles. Endurance muscle testing is a more global assessment of muscle capacity as opposed to individual muscle assessment via EMG. Isometric endurance testing seems to be cost effective and requires little to no equipment to complete (Moreau, Green, Johnson, & Moreau, 2001). It is easy to perform and objective to administer (Payne, Gledhill, Katzmarzyk, & Jamnik, 2000) and therefore was utilised for assessment of muscular properties with respect to SUP.

The majority of the past studies regarding endurance of the trunk musculature have been centred on back pain rather than sporting populations as researchers claim that inadequate trunk endurance is a risk factor in the development and chronicity of low back pain (Arab, Salavati, Ebrahimi, & Ebrahim Mousavi, 2007; Biering-Sorensen, 1984; O'Sullivan, Mitchell, Bulich, Waller, & Holte, 2006). For a system to carry out its goal or function, it requires stability (Reeves, Narendra, & Cholewicki, 2007). In the spine, stability is required to take load, permit movements and also avoid injury (Reeves et al., 2007). It should be highlighted that greater stiffness doesn't necessarily mean greater function. With training, as co-ordination improves, less co-contraction is required to stabilise and therefore stiffness decreases when force is redirected to propulsive movements (Carolan & Cafarelli, 1990).

In addition to strength, authors have begun to propose that the abdominal muscles play a significant role in this spinal stability due to their ability to maintain low level contractions (Hubley-Kozey, Hatfield, & Davidson, 2010). Logic suggests that if people with low back pain exhibit decreased endurance of their trunk musculature (Arab et al., 2007; Biering-Sorensen, 1984; O'Sullivan et al., 2006) then a training tool which exhibited increases in endurance of the trunk musculature would be of great benefit. The primary ways of inferring muscle endurance around the trunk including the flexors, extensors and lateral flexors of the spine are listed below along with average endurance hold times found in previous research.

4.6.1 Tests of the Extensors of the Spine

The importance of the extensors to postural control and to the prevention of musculoskeletal dysfunction has been discussed previously. It has been found that deficits in extensor strength are evident in people with low back pain lasting greater than four months (Reid et al., 1991). Biering-Sorensen found that good isometric endurance of the back muscles may prevent first time occurrences of low back pain in men (Biering-Sorensen, 1984) while recently Adedoyin has found a lack of endurance to be implicated as a major reason for recurrence and chronicity of low back pain (Adedoyin et al., 2011). This lack of endurance is hypothesised to lead to clinical instability and pain due to intersegmental motion around the neutral zone (Panjabi, 1992b).

Biering-Sorensen's method of measuring trunk extension endurance is the most extensively utilised throughout the literature and can be seen in Figure 14 (Biering-Sorensen, 1984). It is a test which has consistently shown to be a reliable, valid, safe, practical, easily administered and inexpensive measure of back extensor endurance (Adedoyin et al., 2011; Alaranta, 1994).

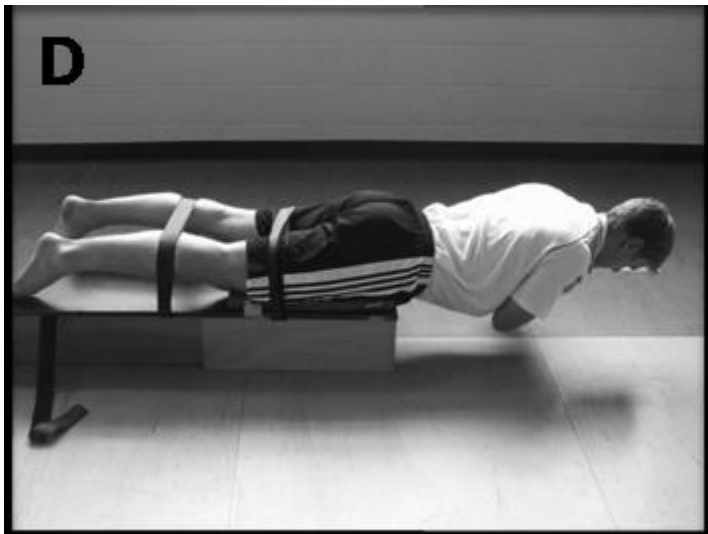


Figure 14: The Biering Sorensen test of endurance of the extensors of the spine from McGill, 2010.

The most recent review in 2006 by Moreau concluded that the Biering Sorensen appears to provide a global measure of back extension endurance capacity (Moreau et al., 2001) as some believe the extensors of the hip are also active during this assessment. The multifidus muscle has been shown to display higher activity via electromyography (EMG) and can be seen to fatigue faster than other perispinal muscles due to this test. It therefore seems that assessment of the extensors of the spine is also indicative of multifidus function and perhaps the gluteals.

Average endurance times for males ranged from 84 to 195 seconds and 142 to 220.4 seconds in females. Reliability ranged from 0.54 to 0.99 with ICC's reported ranging from 0.20 to 0.91 when measuring healthy subjects. The test generally requires the subject to contract the extensors of the back well below the maximal voluntary contraction (MVC) therefore making it safe for even for subjects with back pain. The test was found to be around 20-25% MVC in slim, strong subjects. (Jorgensen & Nicolaisen, 1986) A second review also in 2006 by Demoulin found endurance times for males between 77.8 and 198 seconds and females 85 to 197 seconds (Demoulin, Vanderthommen, Duysens, & Crielaard, 2006). Results of other assessments of extensor endurance can be found in Table 15 below.

Author, Year	Subjects	Males (s)	Females (s)	Group (s)
Biering Sorensen, 1984	n>900 males and females	198	197	
Jorgensen, 1986	N=76 (23females average age 42yrs, 53 males average age 48yrs)	180	207	
Alaranta, 1994	N = 475 males and females			100
McGill, 1999	n=75 (31 males, 44 females)	146±51	189±60	171±60
Stewart, 2003	n=36 coal miners	120.3±33.8		
Leetun, 2004	n=139 athletes	130.4±40	123.4±48.4	
Chan, 2005	n= 32 (age 20.4±1.16) intercollegiate male rowers	114.28±34.62		
Arab, 2007	n=100 (50 males, 50 females)	35±7	36±7	
Champagne, 2009	n= 20 males (average age 24.7± 3yrs)			163±70
Tekin, 2009	n=33 coal miners	128.6±15.2		
Mbada, 2010	n=376 (age 38.9±13.5yrs)			121±49.3
Adedoyin, 2011	n=561 (297 males average age 37.2±13.6, 264 females average age 36.3±12.9)	119±47	106±44	113±46

Table 15: Results from endurance tests of the lumbar extensors from the literature.

4.6.2 Tests of the Flexors of the Spine

Along with endurance of the extensors, the endurance of the trunk flexors is often measured in the literature. Several tests of isometric endurance of the flexors of the trunk flexors have been proposed including the V-Sit and the prone bridge (Durall, Greene, & Kernozek, 2012; Ito, 1996; McGill, Childs, & Leiebenson, 1999). Bridging assessments of lumbar spine endurance have been found to be valid discriminator of symptomatic and asymptomatic individuals (Schellenberg et al., 2007). The prone bridge pictured in Figure 15 has been described as being well tolerated by back pain patients (Durall et al., 2012; Schellenberg et al., 2007). Intraclass Correlation Coefficients have been recorded at 0.95 (Durall et al., 2012) and 0.97 (McGill et al., 1999) for this test of trunk flexor endurance. EMG analysis of the prone bridge shows the rectus abdominus, internal and external oblique most active during this assessment (Schellenberg et al., 2007).



Figure 15: The prone bridge assessment of trunk flexor endurance from McGill,, 2010.

Schellenberg also utilized the prone bridge for assessment of trunk flexor endurance (Schellenberg et al., 2007). Her study found an average endurance hold time of 80.6 ± 41.3 seconds. Similar to the research on extensor endurance in back pain sufferers, a decreased endurance time was also found in duration of the prone bridge amongst symptomatic individuals (28.3 ± 26.8 seconds). Other results from the literature can be seen in Table 16 below.

Author, Year	Subjects	Endurance Time (s)
McGill, 2006	n=401 (5 females, 396 males)	118
Schellenberg, 2007	n=43	80.6 (41.3)
McGill, 2007	n=287 (7 females, 280 males)	129
McGill, 2008	n=390 (10 females, 380 males)	153
Durall, 2012	n=60 (43 females, 17 males)	92.8 (44.4)

Table 16: Results from endurance tests of the lumbar flexors. Values are mean (\pm SD).

McGill's study in 2006 stratified endurance times by age for the prone bridge or plank amongst 401 fire fighters and can be seen in Table 17. He reported that the 40 year old subjects had the longest hold times, and interestingly that females had lower times than males, something which contradicts the majority of findings in previous research on endurance times around the trunk musculature.

Subjects	Age	Average Age	Plank Time (s)
53	20's	25	115
142	30's	35	113
103	40's	45	124
98	50's	53	111
5	Females	35	92
(n=401)		40	118

Table 17: Stratified endurance times from McGill's study of 401 firefighters.

Another test used for assessment of the flexors of the trunk is the V-Sit as seen in Figure 16. The test has reported reliability co-efficients of 0.92-0.93 (Chan, 2005; McGill et al., 1999). Critics of the test state that the head position is difficult to standardise (Durall et al., 2012). Conversely, critics of the prone bridge argue that due to the upper body strength required to sustain the position, individuals with problematic shoulders may terminate the test due to upper extremity fatigue and not trunk muscle fatigue (Durall et al., 2012). Two previous studies have identified disparity between endurance times comparing the two tests and have both concluded that the two tests are measuring different things (Durall et al., 2012; McGill, Belore, Crosby, & Russell, 2010).

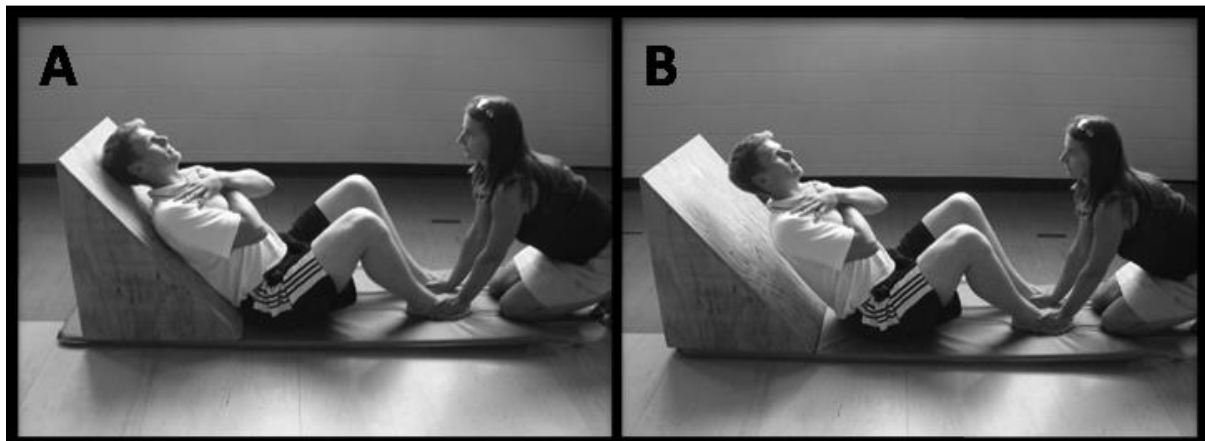


Figure 16: The V sit start position (A) and test posture (B) as per McGill 2010.

Schellenberg reported $52.2 \pm 22.5\%$ MVC for the rectus abdominus and $59.0 \pm 26.6\%$ MVC for the external obliques via EMG for the prone bridge (Schellenberg et al., 2007). McGill's EMG analysis of the V-Sit recorded 37% MVC for the rectus abdominus and 40% MVC for the external oblique with a 35% of MVC recorded for the internal obliques. The extent of the contribution of the hip flexors and other muscles of the lower limb during this assessment is unknown (Durall et al., 2012). It is assumed that keeping the spine in neutral, as is required in the prone bridge, would be better tolerated by back pain patients. It is assumed that maintaining the V-Sit position does have the potential for individuals to flex their lumbar spine under conditions of fatigue (Durall et al., 2012). Due to its global assessment of the anterior trunk, the prone bridge was chosen for the SUP population.

4.6.3 Tests of Lateral Flexors of the Spine

The side bridge has been suggested to challenge the lateral trunk musculature (Evans, Refshauge, & Adams, 2007) and an example can be seen in Figure 17. McGill suggests it optimally challenges the quadratus lumborum (QL), and associated muscles of the anterolateral trunk wall including the internal and external obliques (McGill et al., 1999). The quadratus lumborum is predicted by some to be the best suited major stabilizer of the lumbar spine (Cholewicki & McGill, 1996).



Figure 17: The side bridge position from McGill 2010.

Considerable variation exists in the literature regarding the function of the QL (Park, Tsao, Cresswell, & Hodges, 2012). It has been found to co-contract with symmetrical loading which was inferred to be increasing spinal stability (McGill, Juker, & Kropf, 1996). McGill's study (McGill et al., 1996) found QL to have a contribution to back extension while a study by Andersson (Andersson, Oddsson, Grundström, Nilsson, & Thorstensson, 1996) did not find the same contribution. A possible explanation for the differing results is the discrete regions of the muscle which have been found to have unique activation (Park et al., 2012).

Cadaver studies have shown that the QL is organised in three distinct layers with attachments from the iliac crest to the 12th rib, from the transverse processes of the first four lumbar vertebrae to the 12th rib and from the iliac crest to the transverse processes of the first four lumbar vertebrae (Phillips, Mercer, & Bogduk, 2008). An electromyographic study by Park suggests that the first and third layer may possibly have a spinal stability role (Park et al., 2012). Some authors also delegate some of its function to respiration, due some of the fascicles being attached to the 12th ribs (Phillips et al., 2008). McGill's EMG analysis of the side bridge position demonstrated that the QL was contracting at 54% of MVC, more than any surrounding muscles including the erector spinae, internal and external oblique (McGill et al., 1996). Intrarater reliability during McGill's study using the side bridge was determined to be excellent (ICC>0.97).

Four articles utilizing the side bridge for assessment of the lateral trunk musculature were found in the literature and can be seen in Table 18. Endurance times were all greater on the right side

when compared to the left in all but Greene's study possibly due to the predominance of right hand dominance.

Author	Right Side (s)	Left Side (s)
McGill, 1999	81 (34)	85 (36)
Chan, 2005	98.13 (41.38)	94.53 (32.97)
Evans, 2007	104.8 (44.1)	103.0 (41.3)
Greene, 2012	76.4 (34.5)	77.1 (33.2)

Table 18: Normative data for the side bridge

One negative aspect of utilising endurance tests is that they are subjective and potentially terminated before a true indication of maximal endurance has been reached. Although they are used extensively in the literature, isometric tests of endurance can be hard to standardise and difficult to control due to the contribution of interpersonal factors such as motivation, which can potentially limit endurance times (Durall et al., 2012).

Research shows that these measured endurance times can be increased with training. Carter has shown that over 10 weeks of core stability training twice a week for 30 minutes, significant improvements in back endurance tests can be achieved (Carter, Beam, McMahan, Barr, & Brown, 2006). The two tests included were the side bridge and the static back endurance test. Sekendiz demonstrated that increases in strength, endurance, flexibility and dynamic balance could be achieved in sedentary women with the use of a Swiss ball (Sekendiz, Cuğ, & Korkusuz, 2010). The results of this study lead the authors to recommend the Swiss ball exercise protocol designed to increase core strength for a preventative training method against low back pain in sedentary women.

Prone bridging has been found to challenge the core flexors while supine bridging challenges the core extensors, both of which have been found to be decreased in low back pain subjects (Schellenberg et al., 2007). A measure of the isometric endurance of the lumbar flexors, extensors and lateral trunk as performed previously in the literature, would demonstrate the potential for stability around the lumbar spine amongst paddle boarders. It would therefore appear to be an effective measure of the potential postural control of the lumbar region amongst this population. It is assumed therefore that exposure to core stability training via a paddle board would manifest an increased ability for trunk muscle endurance hold times as seen

previously in the literature. The assessment of trunk muscle endurance of a population of SUP participants utilising these isometric tests was performed in paper 3 – profiling the sport of stand up paddle boarding on page 128.

4.7 The assessment of balance in other sports

Advocates for training on stand up paddle boards will anecdotally report its benefit to balance training, due to the dynamic environment in which it is performed. In order to assess the viability of this claim, a method of assessment for static and dynamic postural control for SUP athletes is required.

The measurement of postural sway via force platforms is well documented in previous studies (Egerton, Brauer, & Cresswell, 2009; Era & Heikkinen, 1985). It has several potential applications in sports medicine including selection of skilled athletes, study of biomechanics of sports which require high levels of postural control and prevention and treatment monitoring of sports injuries (Rogind, Simonsen, Era, & Bliddal, 2003). Measurements with such force platforms have been shown to be reliable (Alaranta, 1994; Era & Heikkinen, 1985). Data can be obtained regarding the length of sway, area of sway, velocity and frequency of sway (Alaranta, 1994).

An increased centre of pressure measurement is usually indicative of decreased postural stability and has been shown to be a good predictor of falls in the elderly (Lord & Clark, 1996) and has also been associated with low back pain (Byl & Sinnot, 1991). It has been reported that deficits of motor skill and co-ordination have been associated with musculoskeletal disorders (Osborne, Chou, Laskowski, Smith, & Kaufman, 2001). It is unclear however if these deficits could a predisposing cause or simply associated with such disorders (Alaranta, 1994). Low back pain patients in particular have been found to have a greater degree of sway, increased reliance on a hip strategy for postural control and a posterior centre of pressure when compared to healthy individuals (Byl & Sinnot, 1991).

Static balance has been defined as the ability of the body to sustain the body in static equilibrium or within its base of support (DiStefano, Clark, & Padua, 2009). Conversely, dynamic balance has been hypothesised to be more challenging due to the fact that it requires the body to maintain equilibrium when moving from dynamic to static states. Both forms of balance require successful integration of visual, vestibular and somatosensory information to allow fine adjustments to allow the body to remain within its base of support (Stambolieva et al., 2011).

Our previous pilot study on balance in elite stand up paddle boarders found what looked like decreased static balance ability amongst these individuals (Schram, Hing, Climstein, & Walsh,

2014). Although the dynamic balance displayed decreased centre of pressure movements and slow sway velocities, the static balance was similar to elite surfers studied by Chapman in 2008 to which he compared to Parkinsonian patients (Chapman, Needham, Allison, Lay, & Edwards, 2008). Chapman discussed that potentially this sort of balance training seems to allow a flexible strategy to be used for balance control. He argued that perhaps due to surfing being a dynamic sport in which one is constantly assessing their surroundings, perhaps vision is no longer the primary input to balance. Stambolieva has offered the explanation that sensory dominance shifts to the vestibular system with its high sensory threshold which requires a greater amount of sway for this system to be effective (Stambolieva et al., 2011).

A similar decreased reliance on vision in postural sway has also been found in a group of triathletes (Nagy et al., 2004). Some authors have suggested that similar results found in the elderly are potentially from increased muscle activity, however it is unknown whether the increased muscle activity is a contributing factor to increased postural sway or whether increased muscle activation is a compensation for it (Nagy et al., 2007).

It is currently unknown whether an individual's static balance would change when using a training tool such as a stand up paddle board; however it is theorised that dynamic balance parameters would improve. Individuals with prior experience in resistance training are thought to benefit less from instability resistance training as they have had prior experience with similar exercises which would expose them to balance challenges (Kibler et al., 2006).

Under conditions with compliant surfaces or dynamic environments, vision is normally the predominant sensory input for postural control. (Golomer, Cremieux, & Dupui, 1999) Palliard in 2011 showed an increase in postural control and decreased reliance on visual feedback in expert surfers, similar to what Chapman found in 2008 (Chapman et al., 2008; Palliard & Noe, 2006). The authors hypothesised that vision could be used to collect essential information about the environment when not relied upon for postural control. Chapman et al's study identified that it took dynamic perturbations to differentiate amateur from professional surfers as a static posture was not of a high enough demand for the postural control system.

In a study of a similar sport to paddle boarding, kayaking and canoeing, the same shift of senses was not found (Stambolieva et al., 2011). Instead, their hypothesis was that the vestibular system

was utilised due to the sport being conducted in sitting, thus negating the ankle's proprioceptive feedback and forcing a reliance on the visual system.

Perhaps a better measure of postural sway or balance for these athletes would be in response to perturbation, as the sport of paddle boarding is about constantly adjusting to a dynamic environment. Van der Kooij described reaching a quiescent state after perturbation a more critical variable when measuring standing balance (Van der Kooij, Van Asseldonk, & Van der Helm, 2005). Therefore, a study on paddle boarding would need to include a dynamic balance component as well as a static one.

For the purposes assessing SUP athletes for postural control, a review of balance assessment amongst athletes, inclusion criteria was an athletic population, utilising a force platform for centre of pressure monitoring while standing on both legs. In total, fourteen articles met the criteria for inclusion and are displayed in Table 19. The majority of prior research shows that athletes display better balance than non-athletes and elite athletes show superior balance to amateur athletes. It would be assumed therefore that elite SUP athletes would display superior balance to their amateur counterparts due to greater exposure to the activity with an overall increase in training activity and competition. Postural control methodology reported previously will therefore be utilised for assessment of balance ability amongst a SUP population. It is imperative that a dynamic component be incorporated into the testing due to the dynamic nature of the environment in which it is performed. The assessment of both static and dynamic balance ability of SUP athletes utilising force was therefore performed in paper 3 – Profiling the sport of stand up paddle boarding on page 128.

Author, Year	Sport	Balance Assessment	Findings
Niinimaa & McAvoy, 1983 (Niinimaa & McAvoy, 1983)	Rifle Shooters(elite) & Biathletes (experienced & rookie)	Static, at rest, while aiming, 60s before and after 4 mins of exercise	Experienced shooters displayed significantly better balance than the less experienced shooters. Balance was better at rest and before exercise.
Aalto et. al., 1990 (Aalto, Pyykko, & Ilmarinen, 1990)	Rifle & Pistol Shooting vs control	Static Balance, eyes open, eyes shut, with and without competition clothing	Shooters displayed better balance than control, shooters displayed better balance with competition clothing than without.
Era et.al., 1996 (Era, Konttinen, & Mehto, 1996)	Rifle shooters (International vs national vs novice)	Static balance: while shooting	International superior to national. National superior to novice.
Konttinen et.al., 1999 (Konttinen, Lyytinen, & Era, 1999)	Rifle Shooting (International vs national)	Static balance, while shooting & 6 sec before shooting	International level shooters had significantly better balance than national level shooters.
Palliard et. al., 2002 (Paillard, Costes-Salon, Lafont, & Dupui, 2002)	Judo (international vs national vs regional)	Static, eyes open, eyes shut.	No differences between groups.
Perrin et. al., 2002 (Perrin, Deviterne, Hugel, & Perrot, 2002)	Judo & Ballet Dancers	Static: eyes open, eyes shut. Dynamic: rotational oscillations of force platform, eyes open, eyes closed	Judo superior to control in all conditions. Judo superior to Ballet Dancers in static balance with eyes shut.
Nagy, 2004 (Nagy et al., 2004)	Triathletes vs Control (fireman)	Static: eyes open, eyes closed.	Triathletes superior to control and less reliant on vision.
Noe & Palliard, 2005 (Noé & Paillard, 2005)	Alpine Skiers (national & international vs novice)	Static: barefoot and in ski boots Dynamic: (tilt board) barefoot and in ski boots	No difference in ski boots, more elite skiers had inferior balance to amateur when barefoot.
Schmidt et. al. 2005 (Schmit, Regis, & Riley, 2005)	Track Runners & Ballet Dancers	Static: eyes open, eyes shut, on foam.	No difference between the two however small sample size (n=10)
Palliard & Noe, 2006 (Palliard & Noe, 2006)	Soccer (national vs regional)	Static: eyes open, eyes shut	Elite superior to amateur.
Palliard & Noe, 2006 (Palliard & Noe, 2006)	Soccer (national vs regional)	Static: eyes open, eyes shut. Dynamic: (tilt board) eyes open, eyes shut.	Elite superior to amateur in static and dynamic balance.
Chapman et.al. 2008 (Chapman et al., 2008)	Surfing (elite vs recreational)	Static: eyes open, eyes shut, head neutral, head back.	No difference between groups.
Palliard, 2011 (Palliard, Margnes, Portet, & Breucq, 2011)	Surfing (National vs Local)	Static: eyes open, eyes shut. Dynamic: (tilt board) eyes open, eyes shut.	National superior to local surfers in both static and dynamic conditions.
Stambolieva, 2011 (Stambolieva et al., 2011)	Canoe & kayak vs control	Static: eyes open, eyes closed	Canoe and Kayakers displayed increased sway velocity than non-athletes.

Table 19: Balance assessment of varying levels of athletes in sport from the literature

4.8 Summary

Chapter 4 has provided physiological data from other water based sports for comparison to SUP. A high correlation of field based measures of aerobic power and laboratory based assessment of maximal aerobic has been demonstrated to enable future confidence in assessment of SUP participants in the laboratory utilising an ergometer. It also shows the methodological issues with assessing SUP with EMG and that isometric testing may be more suitable to gauge the capacity of the musculature in SUP. Finally static and dynamic balance assessment utilising force platforms was seen to be able to distinguish ability in other sports and therefore seems ideal to assess the balance ability of SUP athletes and therefore was utilised in paper 3 – Profiling the sport of stand up paddle boarding on page 128.

Chapter 5

Profiling the Sport of Stand Up Paddle Boarding

PREFACE

This chapter will profile the sport of stand up paddle boarding by comparing an elite and recreational group of SUP participants to a sedentary control group. A spectrum of SUP participants will be assessed for their physiological profile on the SUP ergometer, previously shown to show high correlation to field based measurements. To determine the muscular capacity of SUP participants, endurance of their trunk musculature will be assessed with the trunk isometric tests reviewed in chapter 4. The static and dynamic postural control of SUP participants will be assessed utilising a force platform, the similar method of assessing balance in sport found in section 4.6 in the previous chapter.

It can be seen that SUP is a sport with minimal research around both the performance aspect and also the health benefits of participation in this new sport. The purpose of this chapter is to utilise the investigative techniques highlighted in the previous chapter to understand more about the individual profiles of participants of this sport from a range of abilities. By using the methods adopted in other studies, the important performance characteristics of SUP can be investigated along with the physiological and musculoskeletal benefits for the everyday person. A study was therefore designed to assess the attributes of importance to SUP across a variety of abilities.

PAPER 3

PROFILING THE SPORT OF STAND UP PADDLE BOARDING

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Introduction

Stand up paddle boarding (SUP) is a new sport and recreational activity, which is increasing in popularity around the world due to its proposed health and fitness benefits and enjoyment (Hammer, 2011). SUP is a hybrid of surfing and paddling in which participants can either distance paddle and/or surf waves (Walker et al., 2010). Many websites anecdotally advocate the use of SUP to increase strength, fitness, core stability, balance and decrease back pain. However, our recent review of the literature found no scientific evidence to substantiate the proposed benefits.

Stand up paddle boarding is an activity in which the participant maintains a standing position on a board similar to a surfboard. However, SUP boards are longer in length (~8-15ft, 2.4-4.6m), thicker (4-8in, 10-20cm) and wider (26-31in, 66-78cm) than traditional surfboards. The SUP participant propels the board across the surface of the water by the use of a long, single-bladed paddle. While the standing position is unstable initially, it is continuously disturbed by the motion

of the board and the movement of the arms whilst paddling, providing a constant postural challenge.

Stand up paddle boarding is low impact, making it suitable for all ages. Participants can utilize almost any body of water to either paddle distances or surf waves and it is therefore an ideal aquatic activity. Advantages to SUP include that it is performed whilst standing and that the participant paddles bilaterally, alternating sides when required. It is a dynamic activity primarily utilising the upper limbs with an isometric trunk muscle component.

As SUP can be performed in a competitive environment, it is assumed that participants would require both aerobic and anaerobic fitness to be successful in distance competition. With a number of competitive SUP endurance events lasting in excess of five hours (Molokai2Oahu), a high level of aerobic fitness appears to be required from its elite participants. Anaerobic fitness is essential for short speed bursts and to catch waves.

A high level of dynamic balance and trunk muscle endurance is required by its participants and are both considered important attributes of a SUP participant. Research has shown that dynamic exercise with isometric contraction of the core muscles can increase the strength of core muscles (Danneels et al., 2001) and that improved core stability occurs when training on unstable surfaces (D. Behm, A. Leonard, M., W. Young, B., W. Bonsey, A, C., & S. MacKinnon, N., 2005b). Core stability training is commonly integrated in later stages of rehabilitation programs due to higher demands on the motor control system and increased electromyographic (EMG) recordings from the abdominal musculature (Vera-Garcia et al., 2000).

The importance of trunk muscle capability is twofold. Multidirectional stability is required in athletic performance to optimise performance and minimize the risk of injury while endurance of the muscles is required to support the passive structures of the spine (McGill, Grenier, Kavcic, & Cholewicki, 2003). It has therefore been suggested that trunk muscle assessment also be multidirectional to ensure that stability in all planes is confirmed (Evans et al., 2007). It is assumed therefore that SUP participants would have both increased postural control and high levels of isometric trunk endurance due to the training effect of the activity.

The rationale for comparison of elite and recreational SUP participants is to identify the physiological and musculoskeletal attributes which differentiate the two groups. An indication of

the fitness attributes of elite SUP participants provides a guideline for an individual wanting to succeed in competitive SUP. The profiling of SUP participants has yet to be quantified, leaving a gap in the scientific literature. Therefore, the purpose of this study was to provide original data regarding the physiological and musculoskeletal profiles of SUP athletes and compare it to sedentary individuals with no previous exposure to the activity.

Methods

This research utilized a cross-sectional observational study design. This study was approved by the University Human Research Ethics committee (RO-1550) and each participant formally consented to taking part in the study prior to any tests being performed. The physiological profile measures included aerobic and anaerobic capacity, blood lipid profile (total cholesterol, high density lipoprotein, low density lipoprotein and triglycerides) and body composition. A musculoskeletal profile included static and dynamic balance assessment and isometric trunk muscle endurance.

A total of 15 elite competitive (10 males & 5 females) SUP participants and 15 recreational SUP participants (10 males, 5 females) were recruited from the Stand Up Paddle Surfers Association (Gold Coast, QLD, Australia). Elite participants were currently actively competing and ranked in the national competition. Participants were without a history of back pain and were free from any physical and psychological impairment. The recreational paddlers were required to have a minimum of 1 year experience in SUP and absolutely no competitive experience in SUP events. The sedentary control group were to have never had any experience on a SUP and have been not participating in any exercise in the last six months.

Participants attended the human performance laboratory where they were assessed for stature (to the nearest 0.1cm) and mass (to the nearest 0.1kg) on a standard medical balance scale (Seca, 700, Hamburg, Deutschland). Body composition and basal metabolic rate was assessed using bio-electrical impedance (BIA), Tanita Body Composition Analyzer MC-980MA, Illinois, USA) as this has been shown to successfully determine body composition (Lukaski, Bolonchuk, Hall, & Siders, 1986). Participants were advised to be rested from exercise for a minimum of 24 hrs, be euhydrated and bladder and bowels emptied prior to the BIA assessment. Bloods lipids were analysed prior to exercise using a portable analyser (Cardiochek, P.A. Indiana, USA) to ascertain

total cholesterol (TC), high density lipoproteins (HDL), low density lipoproteins (LDL) and triglycerides (Trigs).

A continuous graded exercise test using a specialised SUP ergometer (KayakPro SUPergo, Miami, FL, USA) was used to determine maximal aerobic power (relative and absolute). Maximal aerobic power (VO_{2max}) was determined using an automated expired gas analysis system (Parvomedics TrueOne 2400 metabolic system, East Sandy, Utah, USA) which was calibrated prior to each test. The expired gas analysis system meets Australian Institute of Sport accreditation standards for precision and accuracy. The gas analysis software was configured to breath by breath for collection however VO_2 max was determined from the average of 30 seconds of max data collected.

The SUP ergometer VO_{2max} protocol involved participants familiarising themselves with the equipment with a 2 minute warm up at their chosen intensity. The test then started at an initial power output of 5W with a 5W increase each minute until volitional exhaustion. Participants were instructed to paddle as per normal, free to alternate paddling on each side ad libitum. Peak exercise blood lactate levels were determined using a portable lactate monitor (Arkay Lactate Pro Blood Lactate Monitor, Kyoto, Japan) and assessed at peak exercise, 1, 5 and 10 minutes post exercise obtained from the finger. The highest blood lactate level measured was deemed the peak lactate. Participant heart rates were monitored throughout the VO_{2max} test with a 12 lead ECG via telemetry (Mortara X-Scribe, WI, USA).

On the subsequent visit to the laboratory, maximal anaerobic power was determined using the same SUP ergometer (KayakPro SUPergo, USA). Participants were allowed to choose their preferred paddling side on the ergometer to ensure that an indication of their maximal power output could be reached. Participants then paddled maximally for 10 seconds from a stationary start. The maximal power was then determined using specialised software incorporated into the SUP ergometer (eMonitor Pro 2 KayakPro, New Rochelle, NY, USA) which is interfaced with a computer. Other anaerobic power parameters measured included distance covered in 10 seconds and peak speed. A minimum of two days and a maximum of three days were allowed between testing maximal aerobic and anaerobic power.

Static and dynamic postural control was assessed via a portable force platform (Kistler 2812D with Bioware 4.0, 100 Hz sampling rate) with three piezoelectric force sensors used to calculate

the centre of pressure (COP) foot positions. The protocol was similar to methods used previously by Palliard and colleagues (Palliard et al., 2011) in which six postural conditions were tested. Static posture was tested for 50 seconds and dynamic posture was tested on a seesaw for 25 seconds. These conditions were tested with eyes open (EO) and then repeated with eyes closed (EC). The testing order was from most stable to least stable.

Center of Pressure (COP) signals were smoothed using a Butterworth filter with a 10Hz low pass cut off frequency. The 100% square (a square in which all the samples lie) was calculated post collection via the range of both the x and y deviations. The COP sway path length (the total distance travelled by the COP over the course of the trial duration) was calculated via the distance between each sampling point. From the COP excursion, the COP velocity was calculated (velocity=distance/time).

Trunk muscle endurance was measured as per methodologies previously described by McGill (McGill et al., 2010). The endurance of the flexors of the spine was assessed with a prone bridge, lateral flexors with a side bridge and the extensors with a Biering Sorensen. The tests were terminated when the participant could no longer maintain the required position as determined by the tester and that time was recorded.

Statistical Analysis

A one-way analysis of variance was used to compare differences between the groups. A post hoc Tukey analysis was utilised to assess differences between the groups. Alpha was set at $P < 0.05$ *a priori*. All statistical analyses were completed using the IBM Statistical Package for the Social Sciences (SPSS, Version 20.0) software program.

Results

All three groups (n=45) were equally composed of 10 males and 5 females. Of the elite competitors, six were rated amongst the top ten in the world while other competitors were currently competing in the national competition of SUP in Australia. As seen in Table 20, there were no significant differences between the groups with regards to age, stature or mass. Elite SUP participants were on average, younger than both the recreational (-4.9%) and sedentary

groups (-13.8%). The sedentary group possessed the smallest stature with recreational SUP being the tallest compared to both the sedentary (+1.3%) and the elite group (+0.5%). The elite group was also the lightest with less total mass than both the recreational (-0.4%) and sedentary groups (-13.3%). Both elite and recreational groups had significantly lower BMI ($F_{2,42} = 5.367$, $P=0.008$, $\eta^2=0.204$) than the sedentary group (-14.6%, -3.68kg/m², 95% CI [-6.94, -0.42], $P<0.01$, $d=-0.91$ and -15.7%, -3.92kg/m², 95% CI [-7.18, -0.66], $P<0.05$, $d=-0.97$ respectively). There were significant differences in body fat ($F_{2,42} = 13.098$, $P=0.001$, $\eta^2=0.384$) with the elite group the leanest with 31.2% (relative) less fat than the recreational group and 77.4% (relative) significantly less than the sedentary group (-7.14% body fat, 95% CI [-17.68, -6.25], $P<0.001$, $d=-1.91$). There were significant differences between the elite and recreational group when compared to the sedentary group with respect to BMI and percentage body fat ($P<0.05$).

	Elite (n = 15)	Recreational (n = 15)	Sedentary (n=15)
Age (years)	38.2 (9.4)	40.1 (7.4)	43.5 (12.6)
Height (cm)	174.3 (8.0)	175.1 (11.3)	173.2 (9.9)
Weight (kg)	76.5 (10.6)	76.8 (13.1)	86.7 (17.3)
BMI (kg/m ²)	25.2 (2.6)*	24.9 (2.8)*	28.9 (5.1)
Body fat (%)	15.5 (6.7)*	20.3 (6.9)*	27.4 (5.6)

Table 20: Participant demographics (mean±SD), * = significant difference from sedentary (p<0.05).

Blood lipid profiling demonstrated no significant differences between groups in total cholesterol, although elites had lower TC than both the recreational (+15.2%) and the sedentary (+15.2%), which is indicative of lower cardiovascular risk. The elite SUP had a significantly higher HDL ($F_{2,42} = 7.407$, $P=0.002$, $\eta^2 = 0.26$) than sedentary controls (+57.9%, +0.76mmol/L, 95%CI [0.28, 1.25], $P<0.05$, $d=1.45$). Elite SUP also demonstrated a significantly ($F_{2,42} = 5.396$, $P=0.008$, $\eta^2 = 0.20$) lower LDL as compared to controls (-58.2%, -0.99mmol/L, 95% CI [-1.72,-0.25], $P<0.01$, $d=-1.24$). The elite group displayed significantly lower triglyceride ($F_{2,42} = 6.483$, $P=0.004$, $\eta^2=0.24$) levels than the recreational group (-0.55mmol/L, 95% CI [-0.99,-0.11], $P<0.05$, $d=-1.17$) and the control group (-0.58mmol/L, 95%CI [-1.01,-0.14], $P<0.01$, $d= -1.58$). There were no significant differences between the recreational and sedentary groups with respect to triglycerides (Table 21).

	Elite (n = 15)	Recreational (n = 15)	Sedentary (n=15)
Total cholesterol (mmol/L)	4.02 (0.79)	4.63 (1.11)	4.63 (0.67)
HDL (mmol/L)	2.10 (0.47)*	1.64 (0.61)	1.33 (0.55)
Triglycerides (mmol/L)	0.82 (0.19)*†	1.37 (0.68)	1.40 (0.49)
LDL (mmol/L)	1.70 (0.85)*	2.27 (0.93)	2.69 (0.67)

Table 21: Blood lipid profiles, values are mean (±SD), † = significant difference from recreational, * = significant difference from sedentary (p<0.05).

With regard to maximal aerobic power, the VO_{2max} of the elite group was significantly higher in both relative ($F_{2,42} = 83.53$, $P=0.001$, $\eta^2=0.73$) and absolute terms ($F_{2,42} = 24.71$, $P=0.001$, $\eta^2 = 0.79$) as compared to the recreational group (relative = +37.1%, +11.83ml/kg/min, 95% CI [6.53, 17.13], $P<0.001$, $d= 1.72$, absolute = +51.3%, +2.23L/min, 95% CI [1.79, 2.66], $P<0.05$, $d=1.41$) and the sedentary group (relative +114.9%, +23.37ml/kg/min, 95% CI [18.07, 28.67], $P<0.001$, $d= 4.73$, absolute = +85.2%, +1.56L/min, 95% CI [1.12, 1.99], $P<0.001$, $d= 2.67$, Table 3). There was also a significant difference between the recreational and sedentary groups with these two parameters (VO_{2max} relative, +56.8%, +11.55ml/kg/min, 95%CI [6.24, 16.85], $P<0.001$, $d=1.90$, absolute, +33.3%, +0.67L/min, 95% CI [0.23, 1.11], $P<0.005$, $d=0.85$). With regard to gender differences, elite males recorded a mean 46.8, $s = 3.7$ ml/kg/min and elite female's 37.5, $s = 4.2$ ml/kg/min. Recreational participants were lower with a mean score for the males 35.3, $s = 6.6$ ml/kg/min and recreational females 25.2, $s = 4.9$ ml/kg/min while the sedentary males achieved a mean VO_{2max} of 21.9, $s = 3.1$ ml/kg/min and females 17.4, $s = 3.0$ ml/kg/min.

There were no significant differences between groups in regards to respiratory exchange ratio, peak heart rate or peak lactate. The elite group reached 102.7% of their age predicted maximum heart rate (220-age), whilst recreational participant's attained 103.9% and sedentary participants 98.0% of their age predicted maximum heart rate. The peak aerobic power ($F_{2,42}=41.48$, $P=0.001$, $\eta^2=0.66$) achieved was significantly higher in the elite group as compared to the recreational group (+43.7%, +9.27W, 95% CI [3.95,14.59], $P<0.001$, $d=1.32$) and the sedentary group (+188.8%, +19.94W, 95% CI [14.61,25.26], $P<0.001$, $d=4.14$) and also when comparing the recreational to sedentary groups (+101.0%, +10.67W, 95% CI [5.34, 15.99], $P<0.001$, $d=1.76$). A significantly greater peak stroke rate ($F_{2,42}=32.66$, $P=0.001$, $\eta^2= 0.61$), distance covered during the test ($F_{2,42}=34.41$, $P=0.001$, $\eta^2= 0.63$) and peak aerobic speed ($F_{2,42}=49.59$, $P=0.001$, $\eta^2= 0.70$) was

recorded from the elite group when compared to the recreational group (+25.5%, +14.13strokes/min, 95% CI [5.92,22.35], $P<0.001$, $d=1.50$; +48.5%, +244.07m, 95% CI [133.24, 354.91], $P<0.001$, $d=1.68$; +13.0%, +0.25m/s 95% CI [0.08,0.42], $P<0.005$, $d=1.23$) and the sedentary group (+64.7%, +27.33strokes/min, 95% CI [19.12,35.55] $P<0.001$, $d=2.78$; 102.7%, +378.69m, 95% CI [267.86,489.52], $P<0.001$, $d=3.67$; +45.3, +0.68m/s, 95% CI [0.51,0.85], $P<0.001$, $d=4.38$). Significant differences were also observed in peak stroke rate (+31.2%, +13.20strokes/min, 95% CI [4.98,21.42], $P<0.005$, $d=1.55$), distance covered (+36.5%, +134.61m, 95%CI [23.78,245.45], $P<0.05$, $d=1.09$) and peak speed achieved during the test (+28.7%, +0.43m/s, 95%CI [0.26,0.60], $P<0.001$, $d=2.15$) between the recreational and sedentary groups.

The anaerobic test displayed significant differences between all of the groups in all measurements (Table 22). The peak power output ($F_{2,42} = 17.97$, $P=0.001$, $\eta^2 = 0.46$) of the elite group was significantly higher than the recreational group (+42.5%, +10.63W, 95% CI [1.62, 19.63], $P<0.05$, $d=0.94$) and the sedentary group (+165.4%, +22.22W, 95% CI [13.21, 31.23], $P<0.001$, $d=2.39$). There was also a significant difference between the recreational and sedentary group (+86.3%, +11.59W, 95% CI [2.58, 20.59], $P<0.01$, $d=1.20$). The peak speed of the elite group was significantly higher than the recreational (+18.1%, +0.37m/s, 95% CI [0.06,0.67], $P<0.05$, $d=1.13$) and the sedentary groups (+45.1%, +0.73m/s, 95% CI [0.43,1.04], $P<0.001$, $d=2.67$) and the recreational group was significantly higher than the sedentary (+28.7%, +0.36m/s, 95% CI [0.06,0.67], $P<0.05$, $d=1.13$). The elite group covered significantly more distance during the test than the recreational (+19.1%, +3.3m, 95% CI [0.46,6.14], $P<0.05$, $d=0.98$) and the sedentary group (+46.4%, +6.52m, 95%CI [3.68,9.36], $P<0.001$, $d=2.17$). Once again, significant differences were also evident between the recreational and sedentary groups in the distance covered (+22.9%, +3.22m, 95%CI [0.38,6.06], $P<0.05$, $d=0.98$).

Parameter	Elite (n = 15)	Recreational (n = 15)	Sedentary (n=15)
Aerobic Performance			
$\dot{V}O_{2\max}$ (L/min)	3.39 (0.63) ^{†*}	2.44 (0.77)*	1.83 (0.57)
$\dot{V}O_{2\max}$ (ml/kg/min)	43.73 (5.87) ^{†*}	31.90 (7.68)*	20.35 (3.69)
Respiratory exchange ratio	1.13 (0.05)	1.16 (0.11)	1.18 (0.07)
HR _{peak} (bpm)	186.60 (15.00)	187.6 (13.71)	173.93 (17.21)
Peak lactate (mmol/L)	13.70 (3.59)	12.43 (3.56)	-
Aerobic power (W)	30.50 (5.98) ^{†*}	21.23 (7.86)*	10.56 (3.21)
Peak stroke rate (strokes/min)	69.60 (10.59) ^{†*}	55.47 (7.99)*	42.27 (9.02)
Average stroke length (m)	2.19 (0.28)	2.24 (0.27)	2.34 (0.48)
Distance covered (m)	747.59 (128.66) ^{†*}	503.51 (159.97)*	368.90 (68.42)
Peak speed (m/s)	2.18 (0.16) ^{†*}	1.93 (0.24)*	1.50 (0.15)
Anaerobic Performance			
Anaerobic power (W)	35.67 (11.08) ^{†*}	25.04 (11.69)*	13.44 (7.05)
Relative anaerobic power (W/kg)	0.46 (0.12) ^{†*}	0.32 (0.13)*	0.15 (0.06)
Peak speed (m/s)	2.35 (0.32) ^{†*}	1.99 (0.40)*	1.62 (0.31)
Distance covered (m)	20.60 (3.08) ^{†*}	17.29 (3.60)*	14.07 (2.88)

Table 22: Physiological characteristics of elite and recreational SUP. Results expressed as mean (SD).

[†]=significant difference from recreational * =significant difference from sedentary (p<0.05).

Figure 18 shows the elite group had significantly smaller 100% squares than the sedentary group in all but the eyes open – medial to lateral condition and significantly smaller than the recreational group in all but the eyes open and eyes open- medial to lateral condition. There were no significant differences between the recreational and sedentary groups with respect to the 100% square. Overall the eyes open condition displayed the best postural control as indicated by the lowest velocity of sway and smallest 100% square of the static tests for all groups. Under the dynamic conditions the eyes open - anterior to posterior demonstrated the lowest velocity of sway for all groups and the eyes open – anterior to posterior had the smallest 100% square amongst the elite and sedentary group while it was smallest in the eyes open - medial to lateral condition for the recreational group.

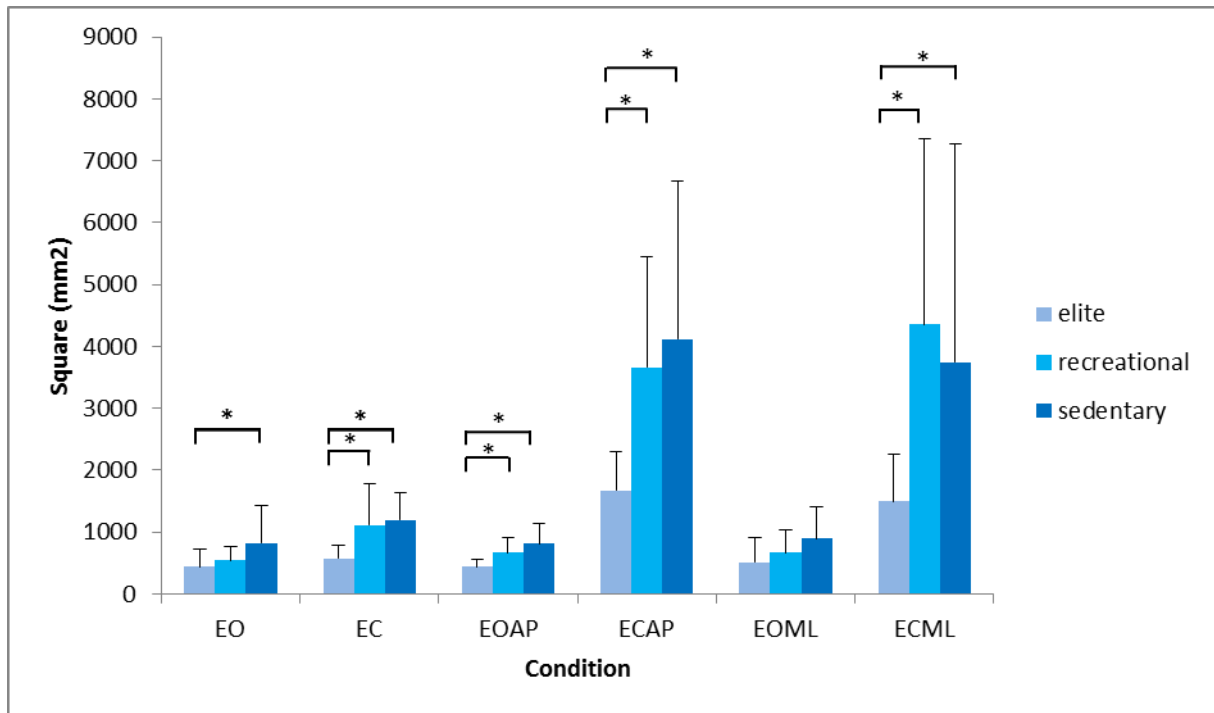


Figure 18: Balance results EO = eyes open, EC = eyes closed, AP = Anterior Posterior Instability, ML = Medial Lateral Instability. Results are expressed as mean±SD. * = Significant difference ($p < 0.05$).

Figure 19 shows that elite group had significantly lower velocity of sway compared to the recreational group in all conditions, and significantly lower velocity than the sedentary group in both dynamic tests with eyes closed (eyes closed - anterior to posterior & eyes closed - medial to lateral). There were no significant differences between the recreational and sedentary groups with respect to velocity. The highest velocities were recorded in the eyes closed – medial to lateral condition for all groups and the greatest 100% square was in the eyes closed – anterior to posterior condition for the elite group and eyes closed – medial to lateral for the recreational and sedentary group. There was a significant increase ($P < 0.05$) in velocity and 100% square for each condition when the subject's eyes were closed as opposed to when they had visual feedback to rely on.

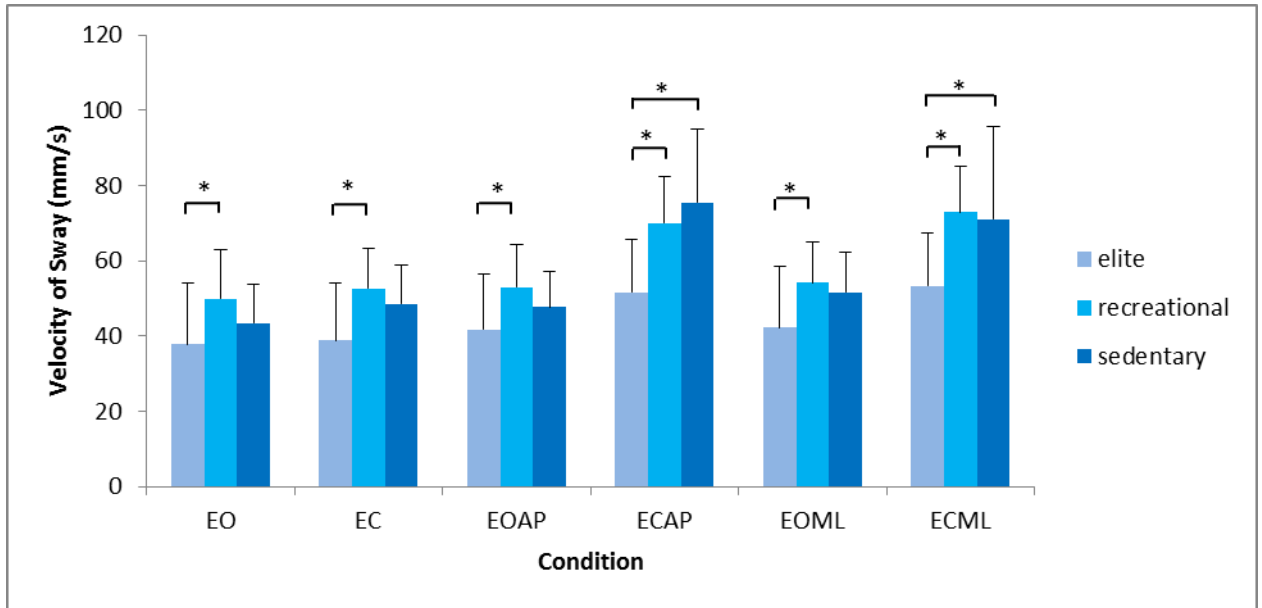


Figure 19: Balance results EO = eyes open, EC = eyes closed, AP = Anterior Posterior Instability, ML = Medial Lateral Instability. Results are expressed as mean \pm SD. * = Significant difference ($p < 0.05$).

Results for the isometric tests (Figure 20) show many significant differences between the three groups. The elite group had significantly longer hold times in the prone bridge ($F_{2,42} = 51.88$, $P = 0.001$, $\eta^2 = 0.71$) than both the recreational (+53.1%, +87.83sec, 95% CI [44.01, 131.65], $P < 0.001$, $d = 1.56$) and sedentary group (+263.4%, +183.67sec, 95% CI [139.85, 227.49], $P < 0.001$, $d = 3.49$). The recreational group also displayed significantly longer hold times than the sedentary group (+137.5%, +95.83sec, 95% CI [52.01, 139.65], $P < 0.001$, $d = 2.58$). The right sided bridge was significantly greater ($F_{2,42} = 30.74$, $P = 0.001$, $\eta^2 = 0.59$) in the elite group than the recreational (+58.3%, +39.73sec, 95% CI [16.97, 62.48], $P < 0.001$, $d = 1.35$) and sedentary groups (+212.2%, +73.36sec, 95% CI [50.60, 96.12], $P < 0.001$, $d = 2.78$). The recreational group showed a significantly longer right sided bridge than the sedentary group (+97.3%, +33.63sec, 95% CI [10.88, 56.39], $P < 0.005$, $d = 1.66$). The left side bridge was significantly ($F_{2,42} = 32.10$, $P = 0.001$, $\eta^2 = 0.61$) greater in the elite than the recreational (+46.4%, +31.62sec, 95% CI [11.20, 52.03], $P < 0.005$, $d = 1.21$) and the sedentary (+207.2%, +67.28sec, 95% CI [46.87, 87.70], $P < 0.001$, $d = 3.26$) while the recreational was significantly greater than the sedentary (+109.8%, +35.67sec, 95% CI [15.26, 56.08], $P < 0.001$, $d = 1.62$).

The elite group demonstrated a non-significant difference in the Biering Sorensen test $F_{2,42} 17.18$, $P=0.001$, $\eta^2=0.45$) with the recreational group (+17.0%) however a significantly higher result in this test when compared to the sedentary group (+109.3%, +77.68sec, 95% CI [44.45, 110.91], $P<0.001$, $d=2.27$). The difference between the recreational group and the sedentary group was also significant (+78.9%, +56.08sec, 95% CI [22.85, 89.31], $P<0.005$, $d=1.46$). There were no significant differences between either group (recreational and sedentary) with regards to right and left bridging.

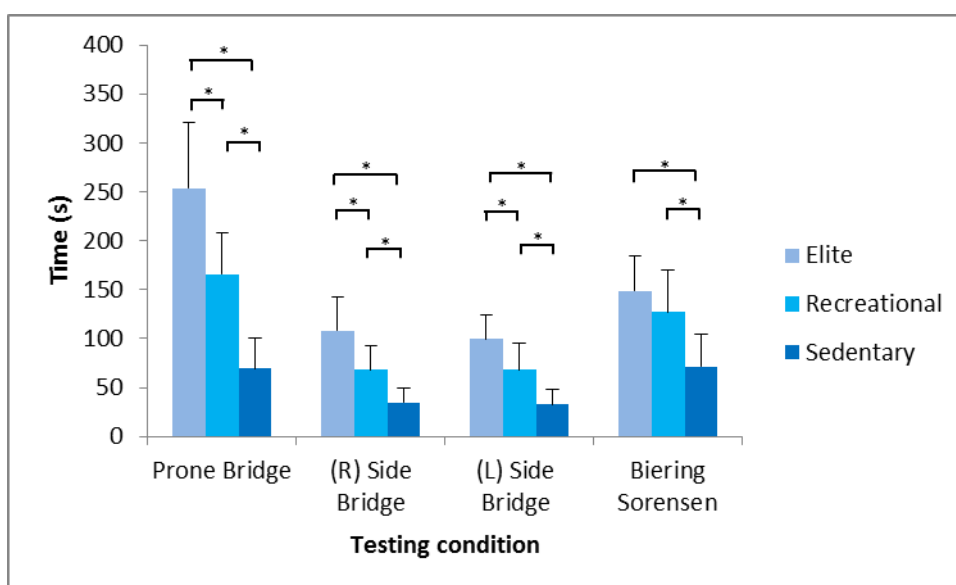


Figure 20: Results of isometric endurance tests. * = significant difference ($p<0.05$).

Discussion

This was the first study to examine the physiological and musculoskeletal profiles of elite and recreational SUP participants as compared to a sedentary population. The lean body composition finding is similar to Ackland's study on the morphological characteristics of the canoe and kayak athletes attending the 2000 Olympic Games in Sydney (Ackland et al., 2003). The elite SUP participants also displayed lower cholesterol, LDL and higher HDL when compared to the recreational and sedentary groups. The elite SUP group demonstrated lipid profiles within the recommended guidelines set by the Australian Heart Foundation; total cholesterol $< 5.5\text{mmol/L}$, HDL $> 1.0\text{mmol/L}$, LDL $< 2.0\text{mmol/L}$ and triglycerides $< 1.5\text{mmol/L}$ (Tonkin et al., 2005). The low BMI, high HDL and low LDL and body fat percentage of the elite groups are possibly associated with the training effect of SUP, beckoning further investigation of the actual health benefits of SUP on cardiovascular risk.

The elite participants profiled in this study displayed comparable levels of maximal aerobic power as seen in other water sports which are upper limb dominant. Previous research has reported surfer's maximal aerobic fitness ranging from 37.8ml/kg/min to 54.2ml/kg/min (Loveless & Minahan, 2010a; Meir et al., 1991), canoeists from 44.2ml/kg/min to 51.9ml/kg/min (Bunc & Heller, 1991; Hahn et al., 1988) and dragon boat racers from 42.3ml/kg/min to 50.2ml/kg/min. It should be noted this group included males and females. If adjusted for only the males group the average of 46.84ml/kg/min is comparable to the numbers reported previously.

Caution should be used when comparing an upper limb dominant sport with full body water based sports such as rowing and swimming due to the larger muscle mass utilised. It has previously been reported that decreases of 39.36% in VO_2 max when being tested on a treadmill versus being tested on a swim bench (Lowdon et al., 1989). If a factor of this decrease is added to the figures reported, measures of 65.28ml/kg/min are achieved, which is comparable to other elite athletes of full body water based sports such as rowing (62.88ml/kg/min) (Jurimae et al., 2000) and swimming with 58.4ml/kg/min (Roels et al., 2005). Also, to our knowledge, no studies have compared the power output of these various upper limb dominant sports.

The necessity to use caution when comparing aerobic power amongst SUP to other sports is indicated by the results from the sedentary group. In this study, average aerobic power outputs of 21.85 ml/kg/min from the sedentary males and 17.37 ml/kg/min from the females are much lower than previously reported references. Age stratified measures of 35.6, $s = 7.7$ ml/kg/min have been reported from sedentary males and 27.2, $s = 5.0$ ml/kg/min from sedentary females when utilising cycle ergometers to assess maximal aerobic power (Herdy & Uhlendorf, 2011).

There was a difference in aerobic power outputs reported previously utilising ergometers such as swim bench and rowing ergometers to these SUP results (Farley et al., 2012; Loveless & Minahan, 2010a). Aerobic power outputs amongst surfers using a swim bench have reached 199W (Loveless & Minahan, 2010a) and 118W to 158W using modified kayak ergometers (Farley et al., 2012; Mendez-Villaneuva & Bishop, 2005). Other water sports have also exhibited large aerobic power outputs including 239W from kayakers (Billat et al., 1996) 371W from rowers (Jurimae et al., 2000) and 195W from dragon boat racers (Ho et al., 2012). It is assumed that due to the extensive amount of muscle mass used for stabilization, a small percentage of muscle force may actually contribute toward propulsion of the SUP across the water.

Although there was a greater average stroke length of the sedentary group when compared to the recreational (+4.46%) and the elite group (+6.85%) in the aerobic test, this does not necessarily reflect a better stroke. It can be seen that the stroke rate achieved by the elite group is significantly higher than the recreational group (+25.5%) and sedentary group (+64.7%) and a shorter more powerful stroke is more beneficial to overall performance as indicated by a much greater power output amongst the elites than the recreational group (+43.7%) and the sedentary group (+188.8%). This higher stroke rate with a shorter stroke distance is related to greater power output, and therefore an increased speed across the water. The inversely proportional relationship found between stroke length and rate is also found in swimming, rowing and outriggering and both of these variables are found to be directly proportional to performance (Sealey, Ness, & Leicht, 2011).

The anaerobic power outputs measured in this study are below those recorded in other water based activities including surfing (205W - 348W, (Loveless & Minahan, 2010b)), swimming (304W, (Hawley & Williams, 1991)), surf lifesaving (326W (Morton & Gaston, 1997)) and kayaking (223W, (Fry & Morton, 1991)). The low numbers could be due to the high amount of muscle activity being used for stabilization on a dynamic surface and consequently minimal muscle activity being used for the overall propulsion. Given our findings, particularly the high levels of maximal aerobic and anaerobic capacity amongst its participants, SUP may be useful for cross-training or athletes wishing to avoid impact after minor injury whilst still developing or maintaining aerobic and anaerobic fitness.

The potential health benefits of SUP should also be considered. Both elite groups and recreational groups had good to very high maximal oxygen consumptions and favourable lipid profiles. For example, over 83% of SUP participants (elite and recreational combined) had total cholesterol levels at target (<5.5mmol/L) and 93% had HDL levels at target (>1.0mmol/L). However participant's diet and activity levels were not assessed and these parameters would have significant influence on lipid profiles. These lipid profiles combined with favourable BMI and elevated aerobic fitness would afford SUP participants with reduced cardiovascular risk, thereby also providing improved health associated with participation.

The elite group displaying a greatest 100% square in the eyes closed - anterior to posterior condition is most likely due to the lack of exposure to the anterior to posterior direction and the familiarity medial to lateral instability encountered when standing on a SUP. Due to the length of

a board, the greatest postural challenge is in the medial lateral direction, possibly explaining why the sedentary and recreational group had the greatest 100% square in the medial – lateral condition. Due to exposure to this condition, their postural control may be increased in this direction amongst the elite.

It can be seen in this study that expertise decreases both the velocity of sway and area indicated by the 100% square during postural challenges amongst SUP athletes. This increased dynamic postural control could be due to specific adaptation due to the sport or alternatively, as Chapman discussed, possible due to a gravitation toward, and subsequent success in balance related activities from those who have a genetic predisposition toward superior postural control (Chapman et al., 2008). It could also be that this way of measuring dynamic balance is not specific for this sport and therefore not a true reflection of the postural control of SUP participants.

It is proposed that instability training stresses the neuromuscular system more than traditional training (Anderson & Behm, 2005) and instability training has been shown to increase knee flexor and extensor strength and also diminish muscle imbalances between dominant and non-dominant sides (Heitkamp, Horstmann, Mayer, Weller, & Dickhuth, 2001). Kidgell demonstrated that six weeks of training on a mini-tramp was as effective as a dura disc for people who have sustained lateral ankle sprains (Kidgell et al., 2007). Whether SUP would have a similar effect on muscle strength, balance and rehabilitation due to it having a similar unstable surface, is currently unclear.

Past studies regarding endurance of the trunk musculature have been centred on back pain with researchers claiming that inadequate trunk endurance is a risk factor in the development and chronicity of low back pain (Arab et al., 2007; Biering-Sorensen, 1984; O'Sullivan et al., 2006). The prone bridge has been used to assess trunk flexor endurance previously, and decreased endurance times as low as 28.3, $s = 26.8$ seconds have been found amongst symptomatic back pain sufferers (Schellenberg et al., 2007). Ranges of between 92 and 124 seconds have been reported from fit, healthy firefighters, (McGill et al., 2010) well below the numbers reported amongst these SUP athletes. The endurance hold times of the lateral abdominal wall measured with the side bridges amongst SUP athletes were similar to an athletic population of 87.5, $s = 36.4$ seconds on the right and 92, $s = 45.8$ seconds on the left (Evans et al., 2007).

The extensor endurance amongst the both SUP groups were similar to previously published papers including McGill's study which showed an average men's endurance time of 146s, women's 189s amongst young, healthy individuals (McGill et al., 1999), higher than Adedoyin's of 119, $s = 47s$ for men and 106, $s = 44s$ for women (Adedoyin et al., 2011), and much higher than Alaranta, who demonstrated 97s men and 87s women (Alaranta, 1994). Results obtained in this study are also greater than a group of athletes who had back pain with an average hold times of 107.5s (Stewart, Latimer, & Jamieson, 2003).

It has been demonstrated previously that the endurance of the core muscles can be improved with core training (Aggarwal, Kumar, & Kumar, 2010). Significant improvements in hold times of all the above tests were made with six weeks of core training including multidirectional movements and instability with the use of a Swiss ball. As the core muscles seem to be activated by SUP and these athletes demonstrate adequate endurance hold times, perhaps SUP could be used to increase endurance of the core muscles and therefore be used as a prophylactic treatment for back pain.

The minimal difference amongst the SUP participants in regards to left and right bridge times is most probably due to the paddling motion being performed bilaterally, typically alternating on a regular 10-14 stroke basis. Muscle imbalances are rife amongst competitive canoeists and outriggers who paddle on the one side (Stambolieva et al., 2011) and it is thought that muscle imbalance could be related to injury occurrence (Franettovich, Hides, Mendis, & Littleworth, 2011). The slightly higher, difference right sided bridge score is hypothesised to be due to the prevalence of right hand dominance.

The aim of this investigation was to profile SUP in regards to physiological and musculoskeletal parameters. In summary, there appears to be a high level of aerobic and anaerobic fitness, dynamic postural control and a high level of trunk muscle endurance amongst those who participate in SUP. It would appear as though greater levels of fitness, strength and balance are associated with higher participation.

Chapter 6

The Acute and Chronic Effects of Stand Up Paddle Boarding

PREFACE

The final aim of this thesis was to determine the effects of stand up paddle boarding on the previously untrained individual. An overview of this chapter is presented in Figure 21. In this chapter, Stand Up Paddle Boarding was used as a training intervention to determine the extent of its benefits of a wide range of health and fitness parameters. In section 6.1, the results from this training intervention are then compared to the results of the recreational and elite groups presented in chapter 5. Both the acute and chronic effects are highlighted with a long term follow up over a full year presented in section 6.2.

The significance of the findings from the intervention study and the dire need for change are discussed in section 6.3 along with the relationship between inactivity and disease found in 6.3.2. This relationship includes both physical and psychological disease as highlighted in section 6.3.3.

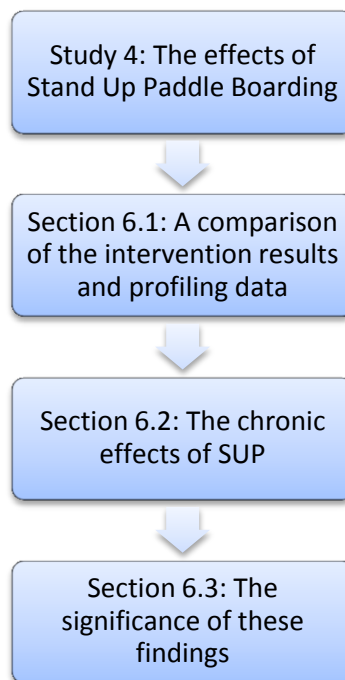


Figure 21: An overview of Chapter 6

Profiling SUP athletes in the previous studies have demonstrated that those who participate in SUP possess high levels of fitness, strength and balance. As correlation doesn't necessarily equate to causation, and our desire to determine the effects of stand up paddle boarding, a study utilising SUP as a training intervention was designed. Advocates for SUP will highlight its benefit for health, fitness and wellbeing which, in the Western world, is an important issue.

PAPER 4

THE EFFECTS OF STAND UP PADDLE BOARDING

**Schram, B., Hing, W., Climstein, M. (2015) The effects of stand up
paddle boarding. *Submitted to the International Journal of
Aquatic Research and Education***

Introduction

Stand up paddle boarding (SUP) originated in Hawaii in the 50's and is a mixture of both surfing and paddling. It is an emerging recreational activity which has attracted attention for its proposed fitness, strength and balance benefits. However our recent review of the literature has identified minimal scientific evidence to substantiate the proposed benefits.

Physical activity is well understood to increase cardiovascular fitness which is associated with cardiovascular mortality (Kessler, Sisson, & Short, 2012). Physical inactivity is a major modifiable risk factor of a range of non-communicable diseases such as diabetes mellitus, osteoporosis and some forms of cancer (George et al., 2012). Physical activity significantly improves overall health, lowers the risk of heart disease by 40%, stroke by 27% and lowers the incidence of hypertension by almost 50% (Exercise is Medicine, 2008). Physical activity has also been associated with improved mental health and well-being, minimizing the risk of developing Alzheimer's and depression (George et al., 2012).

Our prior research has demonstrated that high levels of aerobic and anaerobic fitness, core strength and balance are possessed by those classed as elite amongst this sport. Currently there is little scientific evidence for the anecdotal claims of benefit of this activity and it was therefore our intention to assess the benefit of SUP on a group of sedentary, untrained individuals with respect to fitness, strength, balance and self-rated quality of life.

Methods

A training study in which the aerobic and anaerobic capacity, blood lipid profile, body composition, isometric core strength, static and dynamic balance ability and self-rated quality of life rating of a group of sedentary individuals was monitored over an intervention period of six weeks Figure 22. These measures were recorded initially, before a six week control period, before the training intervention and post intervention to determine the effect of SUP on the various health and well-being parameters.

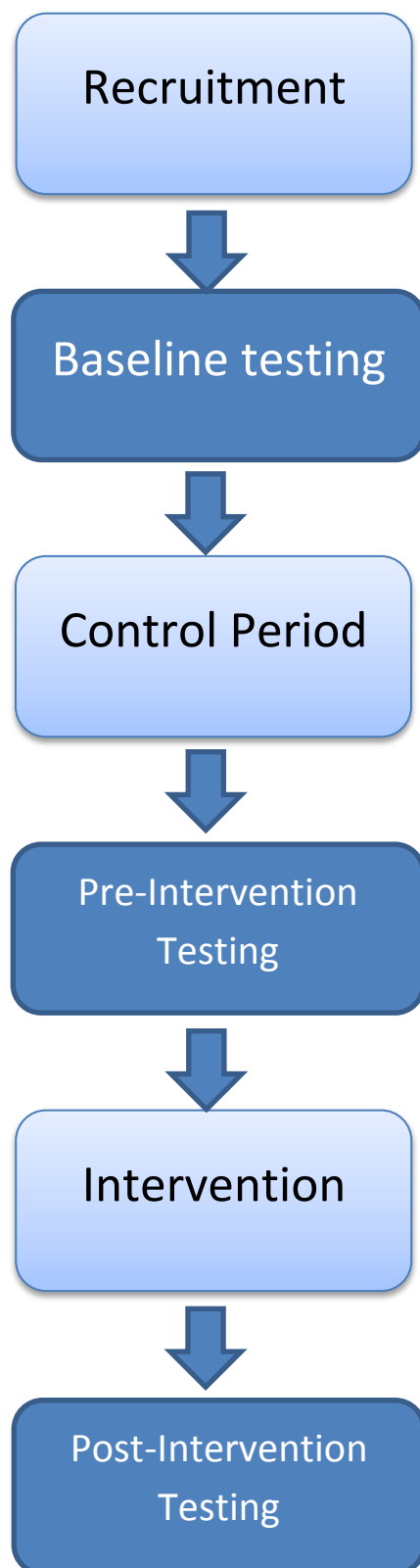


Figure 22: Study design

A total of 18 sedentary individuals (10 males, 8 females) were recruited through radio and media advertisements about the study. A total of 13 individuals (4 females, 9 males) completed the training program. Inclusion criteria required individuals to have not been participating in physical activity for the last 6 months and were aged between 18-60 years. Exclusion criteria included a history of back pain, physical and psychological impairment. The study was approved by the University Human Research Ethics Committee (RO-1550) and each participant formally consented to taking part in the study.

The training program consisted of three one hour sessions per week for six weeks. Participants were given longer, wider boards to begin with (~11' length, 33" width, 4.6" thickness), before moving on to shorter, narrower boards (~length 9'1, 29.5"width, 4.4" thickness) to challenge postural control more as the weeks progressed. The intensity of the sessions was gradually increased until week three where high intensity sprint based training was incorporated into the week with the long slow sessions. Initially, participants were paddling 1km in an endurance session, which increased to 10km by then end of the training program. High intensity initially involved 2 minutes of 10 seconds paddling, 10 seconds resting which progressed to 5 minutes of 10 seconds on, 10 seconds off.



Figure 23: Sedentary individuals undergoing the SUP training intervention.

For testing, participants attended the Water Based Research Unit human performance laboratory where they were assessed for height and weight on a standard medical balance scale (Seca, 700, Hamburg, Deutschland). Body composition and basal metabolic rate was assessed using bio-electrical impedance (Tanita Body Composition Analyzer MC-980MA, Illinois, USA) as this has previously been shown to accurately determine body composition (Lukaski et al., 1986). Bloods lipids were analysed prior to exercise using a portable analyser (Cardiochek, P.A. Indiana, USA) to ascertain total cholesterol (TC), high density lipoproteins (HDL), low density lipoproteins (LDL) and triglycerides (Trigs).

A continuous graded exercise test on a specialised SUP ergometer (KayakPro SUPERgo, Miami, FL, USA) was used to determine maximal aerobic power (relative and absolute). Maximal aerobic power ($\dot{V}O_{2\max}$) was determined using an automated expired gas analysis system (Parvomedics TrueOne 2400 metabolic system, East Sandy, Utah, USA) which was calibrated prior to each test. The gas analysis software was configured to breath by breath however $\dot{V}O_2$ max was determined from the average of 30 seconds of max data collected.

The SUP ergometer $\dot{V}O_{2\max}$ protocol involved participants starting at an initial power output of 5W with a 2W increase each minute until volitional exhaustion. Participants were instructed to paddle as per normal, free to alternate paddling on each side ad libitum.

On the subsequent visit to the laboratory, maximal anaerobic power was determined using the same SUP ergometer (KayakPro SUPERgo, USA). Participants were allowed to choose their preferred paddling side on the ergometer to ensure that an indication of their maximal power output could be reached. Participants then paddled maximally for 10 seconds from a stationary start. The maximal power was then determined using specialised software incorporated into the SUP ergometer (eMonitor Pro 2 KayakPro, New Rochelle, NY, USA) which was interfaced with a computer. Other anaerobic power parameters measured included distance covered in 10 seconds and peak anaerobic speed. Participant heart rates were monitored with a 12 lead ECG via telemetry during both maximal tests. A minimum of two days and a maximum of three days were allowed between testing days.

Postural control was assessed via a portable force platform (Kistler 2812D with Bioware 4.0, 100 Hz sampling rate) with three piezoelectric force sensors used to calculate the centre of pressure (COP) foot positions. Static and dynamic postural control was assessed as per Palliard (Palliard et

al., 2011). Static postural control was assessed for 50 seconds while dynamic postural control on a seesaw was assessed for 25 seconds. These conditions were tested with eyes open (EO) and then repeated with eyes closed (EC). The tests were conducted in order from most stable to least stable.

Center of pressure signals were smoothed using a Butterworth filter with a 10Hz low pass cut off frequency. The 100% square (a square in which all the samples lie) was calculated post collection via the range of both the x and y deviations. The COP sway path length (the total distance travelled by the COP over the course of the trial duration) was calculated via the distance between each sampling point. From the COP excursion, the COP velocity was calculated ($\text{Velocity} = \text{Distance} / \text{Time}$).

Trunk muscle endurance assessments were performed as per McGill in which the flexors of the spine were assessed with a prone bridge, the lateral flexors with the side bridge and the extensors with the Biering Sorensen test (McGill et al., 2010). The tests were terminated when the participant could no longer hold the horizontal position as determined by the tester and the time was recorded.

Finally a self-rated quality of life questionnaire (WHO-QoL Bref UK edition) was completed by the participants pre and post training program. It comprises of 26 items across four domains of physical health psychological health, social relationships and environment. It was administered pre and post intervention to assess the effect of a SUP intervention on self-rated quality of life measures.

Statistical Analysis

All statistical analyses were completed using the IBM Statistical Package for the Social Sciences (SPSS, Version 20.0) software program (mean \pm SD) comparing initial test, pre and post testing for the groups. Normality was assessed via Shapiro-Wilk ($p < 0.05$) and visual inspection of the data's histogram and tests of sphericity were also performed to ensure minimising type 1 errors. Peak speed, stroke rate, anaerobic peak speed and anaerobic distance covered were deemed to not be a normally distributed, therefore a Friedman Test was utilised with a post hoc Wilcoxon Signed Ranks test was utilised. All other data was deemed to be normally distributed and therefore a

repeated measure ANOVA was utilised with a Bonferonni adjustment for multiple comparisons performed post hoc to determine statistical significance between groups.

Results

Thirteen participants (46.15 ± 11.63 yrs, 173.79 ± 10.53 cm) completed the training intervention. An overall attendance rate of 90.27% was seen throughout the training program with the primary reasons for missing sessions being family commitments, sickness and minor injury. Of the five participants who did not complete the training program, one suffered an injury which lead to them withdraw, another was unable to attend due to changes in work schedule, one from sickness and the other two did not provide reasons.

There were no significant differences between initial and subsequent testing prior to beginning the training intervention. Participants were, on average, classified as being overweight according to their BMI throughout the training period. Participant's demographics and blood profiling can be seen in Table 23.

	Initial Test	Pre-Training	Post-Training
<i>Body Composition</i>			
Weight (kg)	84.76 (17.22)	85.45 (17.96)	84.91 (16.51)
BMI (kg/m²)	27.98 (4.72)	28.17 (4.82)	28.02 (4.38)
Body fat (%)	26.33 (5.15)	26.74 (5.47)	26.41 (5.13)
<i>Blood Profiling</i>			
Total cholesterol (mmol/L)	4.67 (0.65)	4.72 (0.73)	4.89 (0.68)
HDL (mmol/L)	1.34 (0.48)	1.39 (0.61)	1.61 (0.52)
Triglycerides (mmol/L)	1.46 (0.51)	1.44 (0.93)	1.54 (0.79)
LDL (mmol/L)	2.71 (0.67)	2.77 (0.51)	2.58 (0.84)

Table 23: Body composition and blood profiling. Values are mean (SD).

Table 24 shows many improvements with respect to aerobic fitness. There were significant improvements in absolute aerobic power (+18.86%) and relative aerobic power (+23.57%) at the completion of the training. There were no significant changes in RER, HRmax, and average or peak stroke length. Increases in distance covered (+44.79%) and peak speed (+10.26%) were observed. There was a weak, negative correlation between age of the participants and % of $\dot{V}O_{2\max}$ increase over the study ($r=-0.32$).

There were significant improvements in anaerobic fitness over the training period (Table 24) with a 41.74% increase in anaerobic power output and 42.11% increase in relative power output over the training period. Peak speed increased 15.79% and distance covered in 10 seconds increased 12.37%.

	Initial Test	Pre-Training	Post Training
<i>Aerobic Performance</i>			
$\dot{V}O_{2\max}$ (L/min)	1.79 (0.59)	1.75 (0.56)	2.08 (0.56)*
$\dot{V}O_{2\max}$ (ml/kg/min)	20.25 (3.92)	19.68 (3.70)	24.32 (4.22)*
Respiratory exchange ratio	1.16 (0.07)	1.18 (0.07)	1.14 (0.07)
HR _{peak} (bpm)	171.46 (16.72)	172.31 (16.10)	171.23 (15.14)
Aerobic power (W)	10.52 (3.05)	11.51 (3.24)	15.20 (3.13)*
Average stroke length (m)	2.38 (0.46)	2.42 (0.48)	2.52 (0.40)
Peak stroke length (m)	2.89 (0.66)	2.93 (0.71)	2.96 (0.61)
Peak stroke rate (strokes/min)	41.15 (9.10)	39.62 (5.20)	43.77 (4.71)
Distance covered (m)	366.68 (71.90)	336.21 (101.97)	486.80 (134.64)*
Peak speed (m/s)	1.51 (0.15)	1.56 (0.14)	1.72 (0.12)*
<i>Anaerobic Performance</i>			
Absolute power output (W)	14.08 (6.68)	16.58 (7.72)	23.54 (7.91)*
Relative power output (W/kg)	0.16 (0.06)	0.19 (0.07)	0.27 (0.07)*
Peak speed (m/s)	1.60 (0.32)	1.71 (0.32)	1.98 (0.22)*
Distance covered (m)	14.90 (2.96)	15.28 (2.68)	17.17 (2.48)*

Table 24: Physiological results. Values are mean (SD). * = $p<.05$

There were no significant changes at any stage in static or dynamic postural control of the individuals. This was evident in the lack of significant change in sway path length, velocity and 100% square of the individuals as seen in Table 25.

Parameter		Initial Test	Pre-Training	Post-Training
Static Postural Control				
Eyes open	SPL (mm)	2204.91 (549.52)	2386.37 (674.90)	2371.99 (477.80)
	Vel (mm/s)	44.10 (10.99)	47.73 (13.50)	47.44 (9.56)
	100% (mm ²)	637.24 (346.77)	1013.38 (948.25)	572.47 (236.06)
Eyes closed	SPL (mm)	2474.62 (532.99)	2601.18 (738.19)	2600.05 (385.28)
	Vel (mm/s)	49.49 (10.66)	52.02 (14.76)	52.00 (7.70)
	100% (mm ²)	1209.51 (460.81)	1160.77 (467.17)	1282.42 (781.40)
Dynamic Postural Control				
Eyes open – Anterior Posterior	SPL (mm)	1215.47 (238.58)	1266.98 (344.81)	1271.89 (180.44)
	Vel (mm/s)	48.62 (9.54)	50.68 (13.79)	50.88 (7.22)
	100% (mm ²)	815.24 (307.75)	986.78 (385.58)	823.74 (268.32)
Eyes closed – Anterior Posterior	SPL (mm)	1961.72 (463.10)	2060.71 (623.97)	1914.60 (468.95)
	Vel (mm/s)	78.47 (18.52)	82.43 (24.96)	76.58 (18.76)
	100% (mm ²)	4360.57 (2660.85)	4508.89 (2556.87)	4774.32 (3515.18)
Eyes open – Medial Lateral	SPL (mm)	1325.47 (274.27)	1374.11 (381.81)	1352.98 (166.99)
	Vel (mm/s)	53.02 (10.97)	54.97 (15.27)	54.12 (6.68)
	100% (mm ²)	952.56 (521.14)	1175.98 (517.55)	988.34 (687.01)
Eyes closed – Medial Lateral	SPL (mm)	2282.17 (774.32)	2271.02 (835.68)	2137.33 (579.63)
	Vel (mm/s)	91.29 (31.05)	90.84 (33.43)	85.49 (23.19)
	100% (mm ²)	5757.19 (4831.81)	6071.60 (5639.39)	4978.82 (2524.22)

Table 25: Static and dynamic postural control results, where EO = eyes open, EC = eyes closed, AP = Anterior Posterior Instability, ML = Medial Lateral Instability, SPL = Sway Path Length, Vel = velocity of sway. Results are expressed as mean (SD).

Figure 24 shows significant ($p<0.05$) increases for all strength tests of the core muscles post intervention with a 19.78% increase in the prone bridge and 22.84% and 23.45% increase in the left and right bridges respectively. The Biering Sorensen improved 21.33% post intervention. There were no significant differences between the right and left sided bridges during any stage of testing.

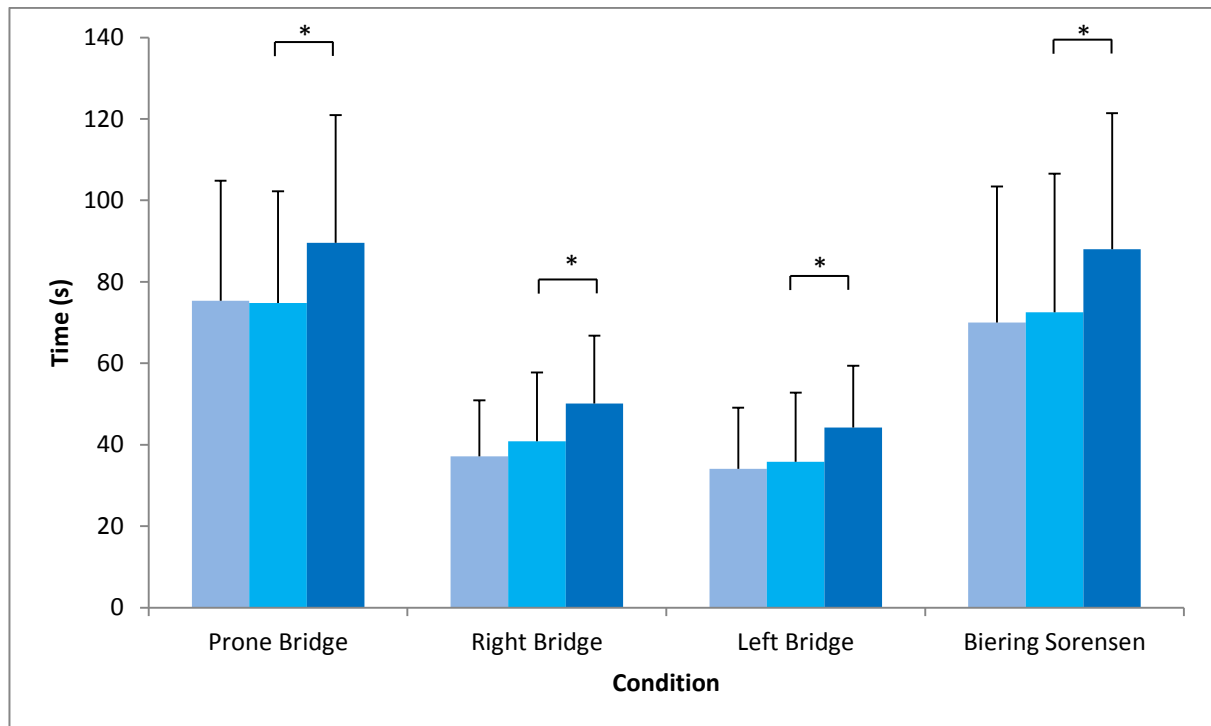


Figure 24: Results from the bridging assessments. Results expressed as mean \pm SD. * indicates $p<0.05$

Quality of life measures were significantly improved across a number of areas (Figure 25). An increase of 9.95% of the self-rated quality of life over the six weeks was seen along with a significant improvement of 28.05% of self-satisfaction with the participants own health ($p<0.05$). The first two domains of Physical Health (+18.99%) and Psychological Health (+17.49%) improved significantly ($p<0.05$) while the other domains of Social Relationships and Environment exhibited improvements of +3.41% and +5.62% respectively (Figure 2).

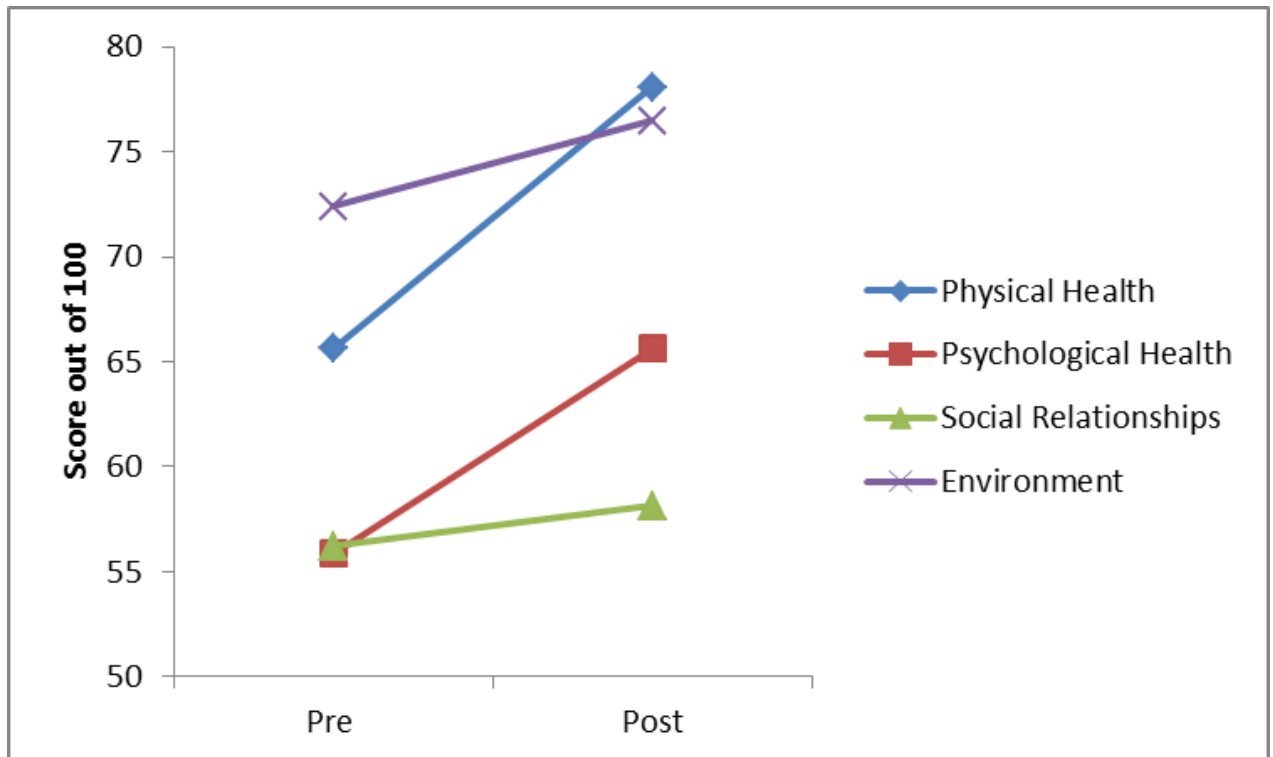


Figure 25: Self-rated Quality of Life results from pre and post intervention.

Discussion

This was the first study to assess the effects of participation in a training intervention of SUP. The aim of this study was to gain an insight into the effects of SUP on fitness, balance, strength and self-rated quality of life on the previously untrained individual.

The slight increase in HDL has been seen previously with aerobic exercise and normally increases in a dose dependent manner (Durstine et al., 2001). Previous increases of 4-22% in HDL and decreases of 4-37% of triglycerides have been reported with aerobic exercise including walking, jogging, swimming and cycling (Durstine, Grandjean, Cox, & Thompson, 2002). Correlations have been seen between training volume and HDL changes in walking jogging and running amongst healthy men (Durstine et al., 2002) and previous studies have reported that 12 weeks is normally the timeframe to see significant changes in HDL, body composition and body weight, perhaps while no significant changes were seen here.

Plasma LDL is normally not lower following aerobic exercise training (Thompson et al., 1997) and is often elevated in people who have a high dietary fat intake (Ziogas, Thomas, & Harris, 1997). Previous investigations suggest that dietary changes in conjunction with exercise do have the capacity to improve total cholesterol, LDL and triglycerides, while exercise alone primarily can have an effect of triglycerides only (Kelley, Kelley, Roberts, & Haskell, 2012). As the dietary habits were not changed in this intervention, the insignificant change in LDL was expected.

Participants in this study were advised to not change any dietary or training habits outside of the SUP training in order to minimize confounding factors on lipids and body composition. Greater body composition changes and HDL changes have previously been reported when combining caloric restriction and exercise training together (Wood, Stefanick, Williams, & Haskell, 1991). This study was restricted to six weeks for funding and participant compliance reasons although it is assumed a longer training intervention amongst this group would further magnify the changes seen. A training intervention specifically targeted at people with a poor lipid profile would be necessary to effectively evaluate SUP as a training tool to change lipid profiles.

Previous studies have utilized various training interventions such as running and cycle ergometry on sedentary populations to ascertain benefits on fitness. The increases in $\dot{V}O_2\text{max}$ this study are comparable to the 33% increase found after high intensity walking/running training at 85-95% HR_{max}, three times per week (Schjerve et al., 2008) and the 22.3% increases in $\dot{V}O_2\text{max}$ over a 12 week training intervention performed three times per week utilizing a cycle ergometer at low intensity of 60-80% W_{max} (Astorino et al., 2013).

Shorter studies over six weeks have found increases of 20.6% utilizing cycle ergometry at 95% $\dot{V}O_2$ reserve, three times per week (Gormley et al., 2008). Other interventional studies have found increases as little as 7.4% (Macfarlane, Taylor, & Cuddihy, 2006), 8.4% (Sijie, Hainai, Fengying, & Jianxiong, 2012) and 2.1% (Lunt et al., 2014). Overall, intermittent, higher intensity training has been shown to elicit greater increases in aerobic power than continuous training over a longer duration.

The large increase (%) found in $\dot{V}O_2\text{max}$ may be explained by the volume of training (180mins/week) and the incorporation of both long-slow low intensity and interval high intensity intermittent training throughout the training program. The incorporation of the higher intensity training would explain the large increases in anaerobic fitness from this study. The increases in

anaerobic power are indicative of an increased capacity of the short term energy systems (ATP-PC). As there was a progressive increase in intensity of training as the program progressed, this would provide an ongoing stimulus for adaptation.

Another explanation for the significant improvement seen in maximal aerobic capacity may be the low baseline fitness levels observed prior to initiation of the training intervention. Other studies have shown significant increases in $\dot{V}O_{2\max}$ when low baselines were recorded (Astorino et al., 2013). Additional evidence of adaptation of the cardiovascular system from this study include the significantly greater distance covered over the duration of the post intervention test, a significantly greater peak aerobic speed and significantly greater peak aerobic power output.

The increases in trunk muscle endurance found in this study are similar to a previously published study utilizing the Swiss ball, where increases in endurance hold times of 30.34% of the extensors of the spine and 57.05% in the side bridge have been found after 10 weeks of training (Carter et al., 2006). Another study found an increase of 45.95% in trunk endurance with a 12 week Swiss ball training program (Sekendiz et al., 2010). It is assumed that a longer training period on SUP would elicit similar gains.

Surprisingly there was no significant change in the static and dynamic balance capabilities of the participants in this study. Previous papers have shown the benefit of balance training on ankle instability subjects over a six week duration indicated by a decreased sway path length measured on a force plate (Kidgell et al., 2007). A study on healthy individuals did show a decrease in both AP & ML parameters of sway over 10 weeks of balance training but was tested in single leg stance (Hoffman & Payne, 1995). For the purposes of specificity, double leg stance was chosen for the balance assessment of the SUP participants. This result could be due to the training period not being long enough to elicit measurable balance benefits or as has been suggested previously, unstable surface training may not be effective for those people who do not have a balance deficit (Schilling et al., 2009). It could also be that the testing protocol is not specific to the demands of this sport and therefore unable to identify any adaptation which may have occurred over the 6 week training program. Although our previous research has shown superior balance ability from an elite population of SUP athletes, it may be that individuals that already possess a high level of balance are attracted to and subsequently succeed in such sports.

Significant improvements in self-rated quality of life measures are in agreement with studies which have found associations between physical activity and quality of life (Rosenkranz, Duncan, Rosenkranz, & Kolt, 2013). Although this was not a group recruited for their quality of life specifically, associations between inactivity and poor self-rated quality of life have been reported previously (Djäv, Wikman, Johar, & Lagergren, 2013). As most of the previous studies utilizing self-rated quality of life measures have been made with populations with health problems, direct comparison of initial and final results are difficult. One study did stratify age and sex with normal values amongst Danish citizens (Noerholm et al., 2004). To use the values from this study which were 77 in Domain 1, 69 in Domain 2, 69 in Domain 3 and 74 in Domain 4, the results at the end of the study compare well to these figures. The primary change in quality of life in this study was in the physical and psychological domains indicative of positive changes in activities of daily living, dependence on substances and aids, energy and fatigue, mobility, pain and discomfort, sleep and rest and work capacity. Positive psychological aspects in the second domain include body image and appearance, negative and positive feelings, self-esteem, personal beliefs and thinking, learning, memory and concentration. As there was no direct influence on environmental or social aspects, the lack of significant change in these areas was expected.

Although it wasn't the primary aim of this study, one participant did report a 20mmHg drop in resting systolic blood pressure following the training intervention. Previous studies have demonstrated the effect of both resistance and aerobic training on blood pressure with reductions in SBP from 141 to 136mmHg with aerobic training (30mins treadmill at 65% $\dot{V}O_2$ max 3x/week for 4 weeks) and 136 to 132mmHg with resistance training (machine circuit at 65% 1RM 3x/week for 4 weeks) (Sharman & Stowasser, 2009). This is clearly in need of more research with higher participant numbers, but given the other associated health benefits, it is not unreasonable to have a positive effect of blood pressure utilizing this sort of activity.

The multitude of benefits from participation in SUP should be acknowledged. Currently sedentary behaviors contribute to ischemic heart disease, stroke, type 2 diabetes, kidney disease, arthritis, osteoporosis, colorectal cancer and depression (AIHW, 2014) and a common barrier to exercise is a perceived lack of time and a dislike of exercise (Kessler et al., 2012). The fact that many physiological, musculoskeletal and psychological benefits can be obtained from participation places SUP as an ideal option for those who are time limited and still looking to improve strength and fitness. Due to it being accessible, relatively easy to learn and low impact on the joints is also of great benefit. The obvious psychological benefits and enjoyment obtained from this activity

delivers an alternate means of aerobic, anaerobic and strength training than the traditional methods.

6.1 A Comparison of the Intervention Results and Profiling Data

For direct comparison to the previous chapters, the results from this intervention were combined with the profiling study. This allows an overall understanding of how much improvement was seen in comparison to other groups who have been utilising SUP for a longer duration. The following section will display the physiological and muscular benefits of the intervention, compared to the other groups.

There were significant improvements in fitness, strength and self-rated psychological measures over the six week training intervention. The improvement in this area seen in the short training period is assumed to be magnified with chronic participation. It is currently unclear if SUP for a longer duration would have a positive effect on body composition, blood lipid profile and static and dynamic balance, measures which were not significantly affected by SUP but have been shown to be associated with exercise participation. Figure 26 shows the intervention results of this thesis in conjunction with the results from the previous profiling study. Although there was significant improvement in aerobic fitness over the duration of the training intervention, there are still significant differences between the post intervention results for aerobic fitness and the recreational group.

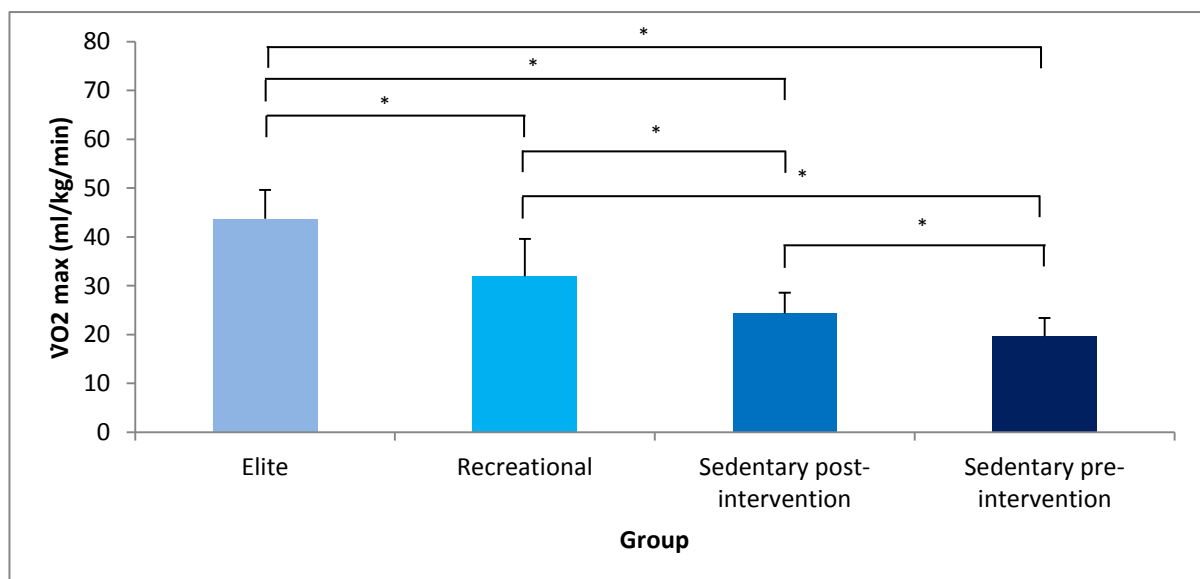


Figure 26: Intervention results with previous research of aerobic fitness

Anaerobic fitness during the training intervention significantly improved during the training intervention to show no significant difference to the recreational group (Figure 27). There is however a significant difference between the post intervention sedentary group and the elite group with respect to anaerobic fitness.

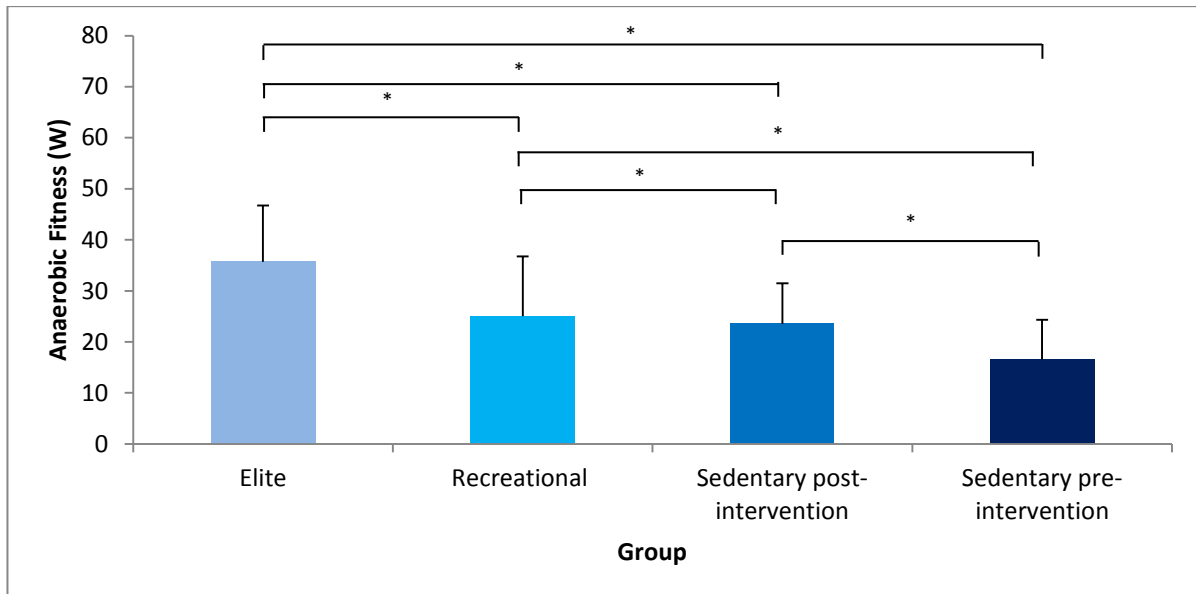


Figure 27: Intervention results with previous research on anaerobic fitness in SUP

Figure 28 demonstrates the prone trunk muscle endurance of the elite, recreational and pre and post intervention groups. There were significant differences between all the groups when pooling the prone bridging data ($p < 0.05$). Despite significant improvements during the training intervention, the recreational group of SUP participants still had a +84.75% greater endurance hold time in the prone bridge than the post-intervention group.

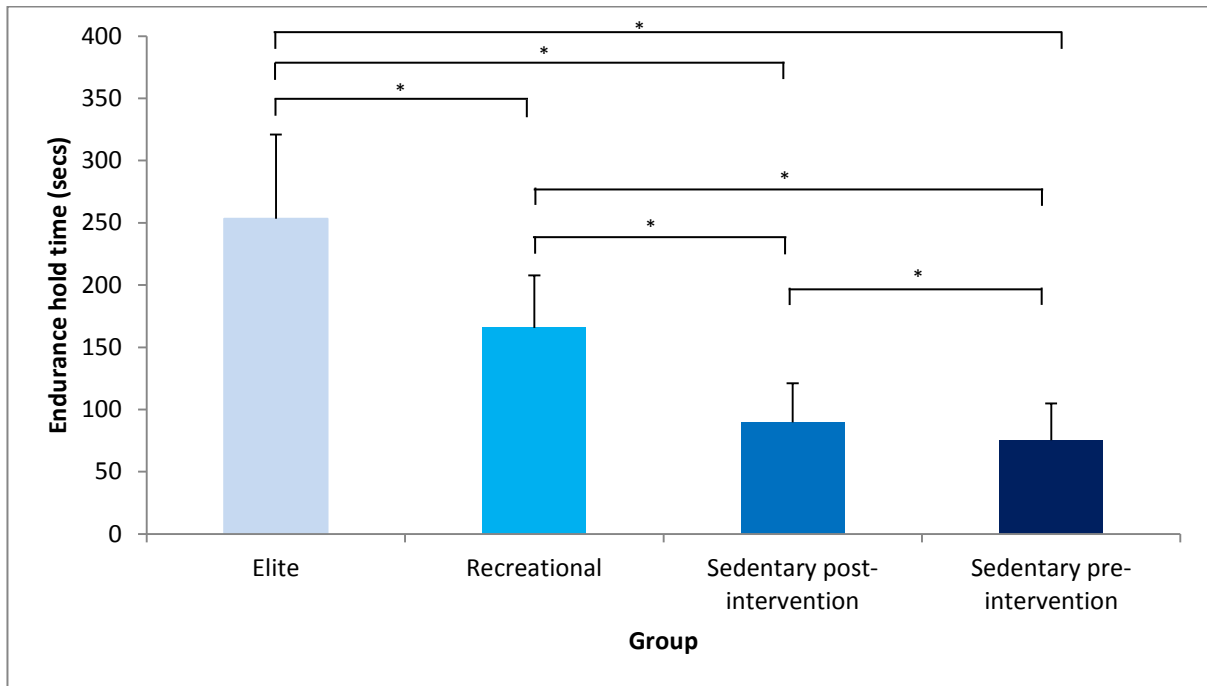


Figure 28: Prone bridging results pooled with the profiling data. Results expressed as mean \pm SD. * = $p < 0.05$

Figure 29 shows the results of the right sided bridge from the intervention pooled with the profiling data. For this test, there were no significant differences between the post intervention group and the recreational group. There was a +35.54% difference between the two groups at this stage.

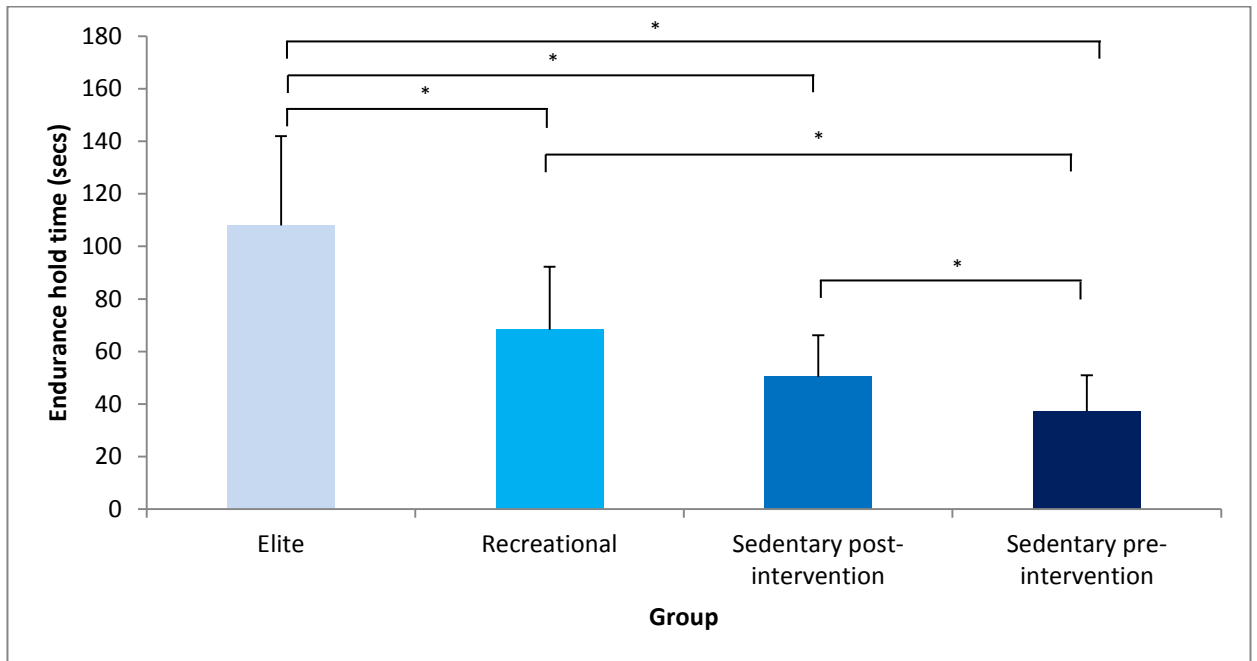


Figure 29: Right side bridging results pooled with the profiling data. Results expressed as mean±SD.

***=p<0.05**

Figure 30 shows the results of the left sided bridge from the intervention along with the pooled profiling data. There are significant differences between all groups ($p<0.05$). The difference in endurance hold time between the post-intervention group and the recreational group was +55.84%.

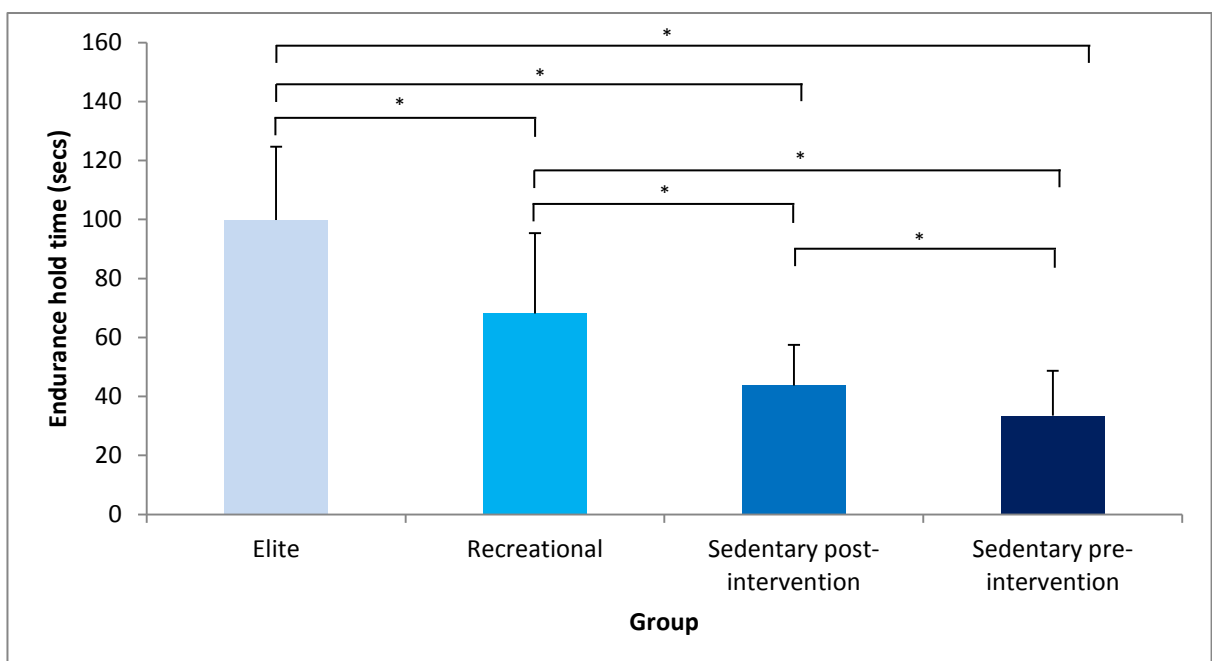


Figure 30: Left side bridging results pooled with the profiling data. Results expressed as mean±SD.

***=p<0.05**

Figure 31 shows the results of the Biering Sorensen isometric test pooled with the profiling data. There were significant differences ($p < 0.05$) in all groups except the elite and recreational as found in the original profiling study. There was a +44.47% greater endurance hold time amongst the recreational group when compared to the post-intervention group.

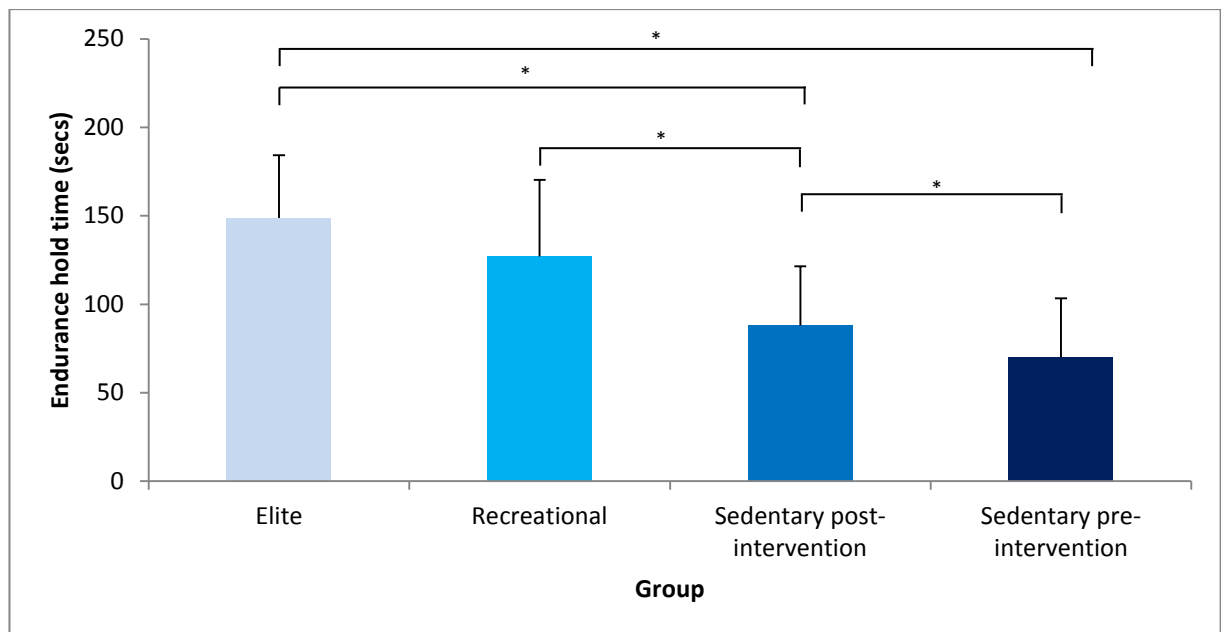


Figure 31: Biering Sorensen results pooled with the profiling data. Results expressed as mean ± SD.

***=p<0.05**

The utilisation of SUP as a training tool can therefore elicit many benefits on the fitness and strength of previously untrained individuals. Anaerobic levels of fitness and right sided bridge endurance after six weeks can improve to be similar to recreational paddlers, however all other levels remain significantly lower than the recreational paddler. It would appear that a timeframe greater than six weeks would be required to possess fitness and strength benefits similar to the recreational group.

6.2 The Chronic Effects of SUP

Introduction

Due to the differences found between the recreational group profiled and the post-intervention group in many of the measured parameters, a greater duration of training was monitored. One year following completion of the SUP training intervention, two participants were available for follow-up testing. They had both continued to participate in fitness classes utilising SUP as a training tool between two and three times per week. They were testing utilising the same methods that were employed for the intervention study conducted previously.

Methods

A total of 2 individuals (1 male, 1 female) were assessed in the Water Based Research Units Laboratory on two consecutive days after one year of participating in SUP classes, three times per week. The study was approved by the University Human Research Ethics Committee (RO-1550) and each participant formally consented to taking part in the study.

For testing, participants attended the Water Based Research Unit human performance laboratory where they were assessed for height and weight on a standard medical balance scale (Seca, 700, Hamburg, Deutschland). Body composition and basal metabolic rate was assessed using bio-electrical impedance (Tanita Body Composition Analyzer MC-980MA, Illinois, USA) as this has previously been shown to accurately determine body composition (Lukaski et al., 1986).

A continuous graded exercise test on a specialised SUP ergometer (KayakPro SUPergo, Miami, FL, USA) was used to determine maximal aerobic power (relative and absolute). Maximal aerobic power ($\dot{V}O_{2\max}$) was determined using an automated expired gas analysis system (Parvomedics TrueOne 2400 metabolic system, East Sandy, Utah, USA) which was calibrated prior to each test. The gas analysis software was configured to breath by breath however $\dot{V}O_2$ max was determined from the average of 30 seconds of max data collected.

The SUP ergometer $\dot{V}O_{2\max}$ protocol involved participants starting at an initial power output of 5W with a 2W increase each minute until volitional exhaustion. Participants were instructed to paddle as per normal, free to alternate paddling on each side ad libitum.

On the subsequent visit to the laboratory, maximal anaerobic power was determined using the same SUP ergometer (KayakPro SUPERgo, USA). Participants were allowed to choose their preferred paddling side on the ergometer to ensure that an indication of their maximal power output could be reached. Participants then paddled maximally for 10 seconds from a stationary start. The maximal power was then determined using specialised software incorporated into the SUP ergometer (eMonitor Pro 2 KayakPro, New Rochelle, NY, USA) which was interfaced with a computer. Other anaerobic power parameters measured included distance covered in 10 seconds and peak anaerobic speed. Participant heart rates were monitored with a 12 lead ECG via telemetry during both maximal tests. A minimum of two days and a maximum of three days were allowed between testing days.

Postural control was assessed via a portable force platform (Kistler 2812D with Bioware 4.0, 100 Hz sampling rate) with three piezoelectric force sensors used to calculate the centre of pressure (COP) foot positions. Static and dynamic postural control was assessed as per Palliard (Palliard et al., 2011). Static postural control was assessed for 50 seconds while dynamic postural control on a seesaw was assessed for 25 seconds. These conditions were tested with eyes open (EO) and then repeated with eyes closed (EC). The tests were conducted in order from most stable to least stable.

Center of pressure signals were smoothed using a Butterworth filter with a 10Hz low pass cut off frequency. The 100% square (a square in which all the samples lie) was calculated post collection via the range of both the x and y deviations. The COP sway path length (the total distance travelled by the COP over the course of the trial duration) was calculated via the distance between each sampling point. From the COP excursion, the COP velocity was calculated ($\text{Velocity} = \text{Distance} / \text{Time}$).

Trunk muscle endurance assessments were performed as per McGill in which the flexors of the spine were assessed with a prone bridge, the lateral flexors with the side bridge and the extensors with the Biering Sorensen test (McGill et al., 2010). The tests were terminated when the participant could no longer hold the horizontal position as determined by the tester and the time was recorded.

Finally a self-rated quality of life questionnaire (WHO-QoL Bref UK edition) was completed by the participants pre and post training program. It comprises of 26 items across four domains of physical health psychological health, social relationships and environment. It was administered pre and post intervention to assess the effect of a SUP intervention on self-rated quality of life measures.

Statistical Analyses

Due to this being a small case study with only n=2, no formal statistical analyses were employed.

Results

The male participant is displayed on the left and female participant on the right of the following figures. It can be seen during the six week intervention period; decreases in weight, body fat and BMI were evident. This trend continued as the training continued over the year (Figure 32). The male lost 7.2kg from the start, decreased his body fat by 5%, reduced BMI by 7.34% while the female lost 3.7kg, 6.6% body fat and her BMI decreased 15.35%.

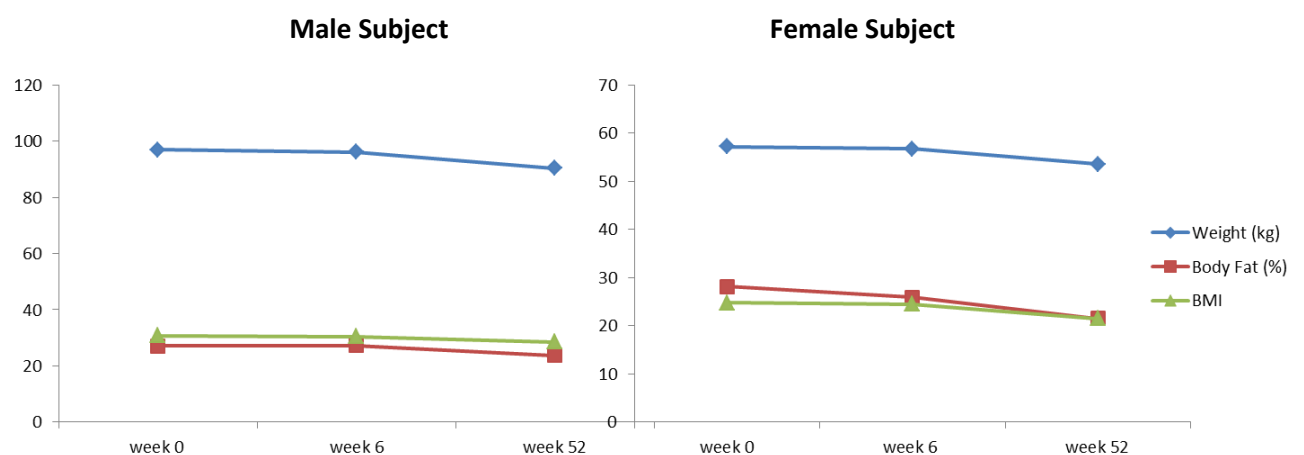


Figure 32: Subject demographics after 1 year.

Figure 33 demonstrates the trunk muscle endurance results for the two individuals over the full year. The improvements made early during the 6 week program also continued to improve over the full year of adherence to the SUP training. The male improved his trunk muscle endurance overall by 70% and the female 147.5% from an average of all four tests.

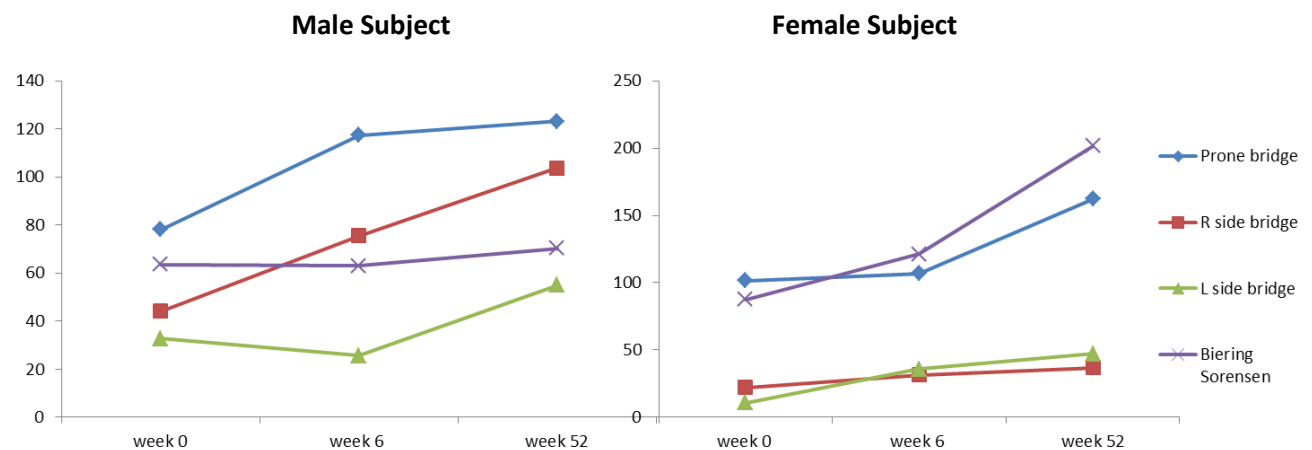


Figure 33: Trunk muscle endurance over 1 year.

Figure 34 shows the fitness improvements of the two participants. The male increased his fitness 25%, while the female improved her fitness 42.15% over the full year. Aerobic power output increased 49% in the male and 48.95% in the female.

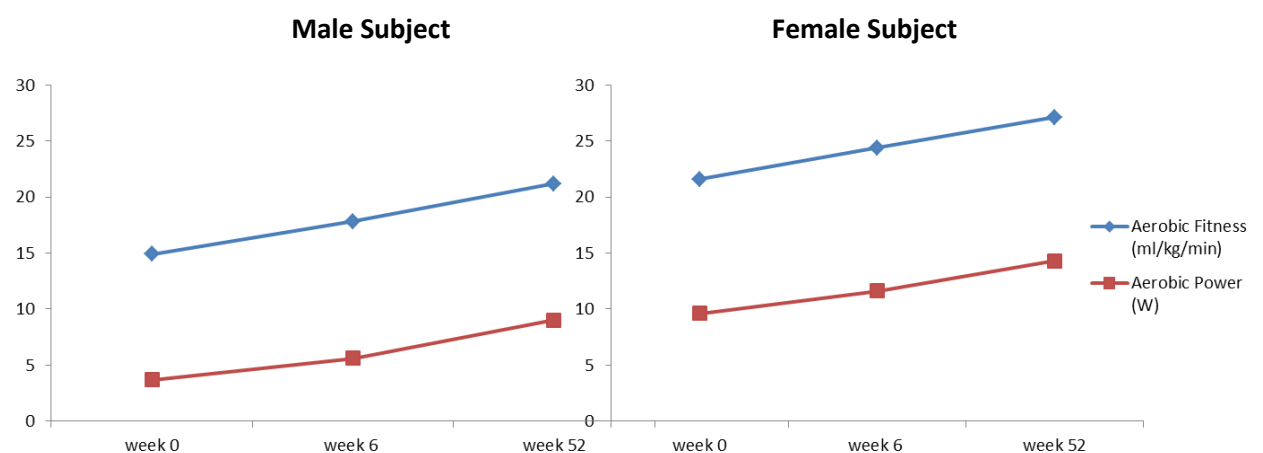


Figure 34: Aerobic fitness results over 1 year.

Figure 35 demonstrates the self-rated quality of life questionnaire results over the year. The two domains of quality of life social relationships and environment were seen to increase in this time frame despite not being significantly altered in the group during the 6 week program. Overall, the male's self-rated quality of life in the physical domain increased 84.09%, 33.93% in the psychological domain and 50% and 58.87% in the social relationships and environment domains respectively. The female's results increased 17.39% in the physical, 33.93% in the psychological, 25.33% in the social relationships and 27.54% in the environment domain.

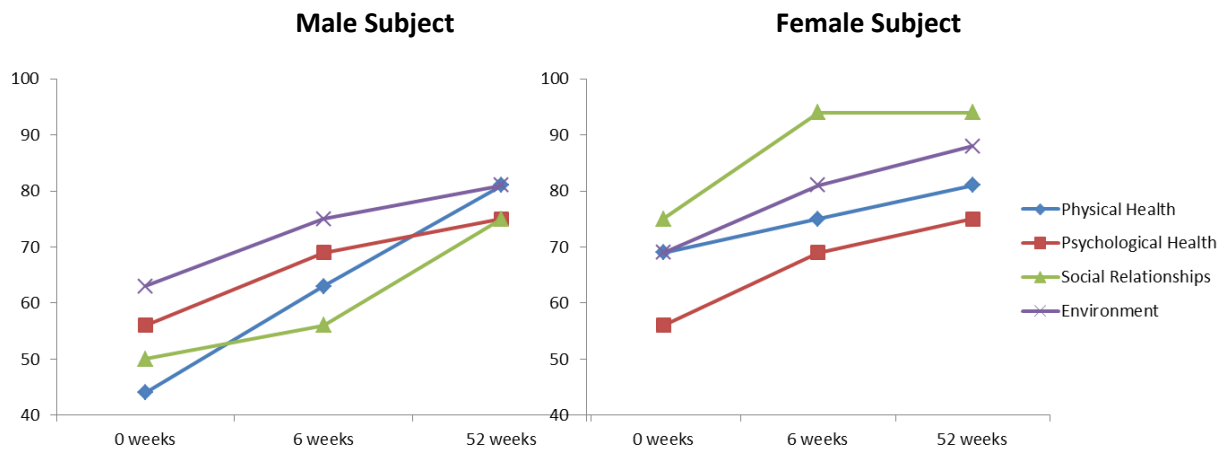


Figure 35: Self-rated Quality of Life after 1 year.

Discussion

Although limited to only two participants, it can be seen that the positive effects during the six week intervention have been maintained at least and increased in some areas as well. The positive effects on fitness, trunk muscle endurance and quality of life were seen to increase over the one year follow up. Of interest, no significant changes in static or dynamic balance ability were seen after a full year of SUP training. This finding may reinforce the previous hypothesis that balance training may only benefit those who have a deficit in their balance or that the method of assessment of balance utilised in this thesis may not be applicable to SUP.

A significant finding during the one year follow up was the improvement in self-rated quality of life as measure by the WHO-QoL BREF. Each individual facet which encompasses the overall domain of the WHO-QoL BREF can be seen in Table 26. It is assumed that the facets in particular which would be affected by chronic participation in SUP would include the personal relationships and social support aspect of the social relationships domain and the participation in and opportunities for recreation/leisure activities in the environment domain. It is assumed that the social aspect of SUP and relationship building amongst its participants may not be elicited in the shorter 6 week timeframe of the prior intervention study. It is also assumed that the plateau in the female's social relationship domain evident in Figure 35 may be due to a ceiling effect.

Domain	Facets incorporated within domains
1. Physical Health	<ul style="list-style-type: none"> • Activities of daily living • Dependence on medicinal substances and medical aids • Energy and fatigue • Mobility • Pain and discomfort • Sleep and rest • Work capacity
2. Psychological	<ul style="list-style-type: none"> • Bodily image and appearance • Negative feelings • Positive feelings • Self-esteem • Spirituality/Religion/Personal beliefs • Thinking, learning, memory and concentration
3. Social Relationships	<ul style="list-style-type: none"> • Personal relationships • Social support • Sexual activity
4. Environment	<ul style="list-style-type: none"> • Financial resources • Freedom, physical safety and security • Health and social care: accessibility and quality • Home environment • Opportunities for acquiring new information and skills • Participation in and opportunities for recreation/leisure activities • Physical environment (pollution/noise/traffic/climate) • Transport

Table 26: Facets incorporated into each domain of the self-rated Quality of Life Questionnaire.

It would appear as though participants who continued to utilise SUP as a training tool continued to reap the benefits from its use. Continuing an exercise regime of just three times per week utilising a SUP seems enough to maintain health and fitness gains and may even lead to greater increases in weight loss, improvements in fitness, trunk endurance and self-rated quality of life, especially in the social relationship and environmental domains.

6.3 The Significance of These Findings

The acute and chronic effects of SUP participation found in the previous sections should be acknowledged. The importance of these findings with the dire health situation facet specifically in Australia will be highlighted in the next section. It highlights both the problems faced with health and also why an intervention like SUP desperately needs to be promoted.

6.3.1 The Current Problem, Why Change is Needed

According to the Global Burden of Disease Study in 2010, musculoskeletal disorders are second only to cancer as the leading cause of disease burden in Australasia (Murray et al., 2012). The study highlights that musculoskeletal conditions affect millions of people of all ages, in all cultures and in all backgrounds. Musculoskeletal conditions often result in pain, disability and loss of both personal and economic independence. Musculoskeletal conditions are the world's second greatest cause of disability and have the fourth greatest impact on health of the world's population in regards to death and disability.

Despite these facts, there are still no prioritized policies directed toward the growing burden of musculoskeletal conditions and their risk factors including obesity, physical inactivity and injuries. The report calls for Australia to do more to address the growing burden of musculoskeletal conditions such as low back pain and osteoarthritis, and suggests that musculoskeletal disorders be allocated the same resources as cancer, mental health and cardiovascular disease. The study's authors have called for urgent action to improve prevention and management of musculoskeletal disorders to keep people moving pain and disability free.

Locally, the most recent report from the Australian Institute and Welfare (AIHW) presents Australia as being unhealthy, inactive and overweight (Australian Institute of Health and Welfare, 2012a). We are currently seeing unprecedented cases of coronary heart disease which remains the leading cause of death for both males and females in Australia. Hypertension and obesity along with tobacco smoking accounted for the greatest disease burden in 2003 in Australia. The AIHW report also estimated that we are currently not partaking in adequate physical activity to benefit our health with participation levels in sport and recreation decreasing, especially in the 25-35 year age bracket. Consequently, obesity rates are increasing, making Australians some of

the heaviest in the world with high rates of hypertension, hypercholesterolemia and impaired glucose regulation.

This increase in rates of cardiovascular disease should not be taken lightly. Cardiovascular disease (CVD) is the leading cause of death in Australia accounting for 33% of all deaths in 2009. Statistics from the Australian Heart Foundation estimate that 1 person dies every 11 minutes from CVD, estimated to cost \$7.9 billion in 2008-2009 in Australia (Australian Institute of Health and Welfare, 2012b). Predisposing factors to the development of CVD include tobacco smoking, physical inactivity, being overweight and obese, diets high in saturated fats, excessive alcohol consumption, hypertension and elevated blood cholesterol levels (Australian Institute of Health and Welfare, 2012a).

Despite the health brief from the AIHW in 2012 reporting that deaths from CVD are down, this drop can primarily be attributed to improvements in management over the past 60 years, not necessarily a decrease in the development of predisposing factors (Australian Institute of Health and Welfare, 2012b). Current estimates indicate that 60% of Australians are overweight or obese, 70% are not getting sufficient exercise, 30% have hypertension and 52% of Australians have elevated cholesterol (AIHW, 2004). Hypertension is responsible to the greatest contribution to the burden of CVD followed by blood cholesterol, physical inactivity and high body mass (Begg, 2007). According to the report, obesity is increasing with males having the 2nd highest rate of obesity in the world, females the 5th (Australian Institute of Health and Welfare, 2012b). These risk factors for CVD are magnified when more than one is present (Trevisan, Liu, Bahsas, & Menotti, 1998).

Stand up paddle boarding could provide a valuable tool to arrest the increasing rates of CVD and its associated predisposing factors. The following pages document validated alterations in these health markers with activity from the literature, and also provides ammunition for the claims of SUP being beneficial for holistic health and wellbeing.

6.3.2 The Importance of Fitness and the Problem with Inactivity

Although the importance of both strength and postural control has been covered previously in this thesis, fitness has not. Numerous studies, both epidemiological and randomised controlled trials, have found that cardiorespiratory fitness provides both primary and secondary prevention of CVD (Nokes, 2009). In addition to CVD, numerous reports have highlighted the importance of physical activity for the prevention of all-cause mortality, cancer, type 2 diabetes and obesity, along with many other chronic diseases (Surgeon General's Report, 1996). Physical activity and cardiorespiratory fitness have also been identified by the American Heart Association as a primary or adjunctive treatment for hypertension, glucose intolerance, poor blood lipid profile, depression, osteoporosis and obesity (Thompson et al., 2003).

Physical activity is defined as bodily movement produced by skeletal muscles that result in energy expenditure beyond resting expenditure (Thompson et al., 2003). Australian recommendations from the Department of Health and Aging for physical activity are currently for 30 minutes of moderate intensity physical activity on most, preferably all days and for regular, vigorous activity for extra health and fitness (Department of Health and Ageing, 2010).

Physical inactivity is a major modifiable risk factor of a range of non-communicable diseases such as diabetes mellitus, osteoporosis and some forms of cancer (George et al., 2012). Physical activity significantly improves overall health, lowers the risk of heart disease by 40%, stroke by 27% and lowers the incidence of hypertension by almost 50% (Exercise is Medicine, 2008). Physical activity has also been associated with improved mental health and well-being, minimizing the risk of developing Alzheimer's and depression (George et al., 2012).

Despite these figures, estimates indicate that up to 60% of Australians reported inadequate levels of physical activity between 2007 and 2008. The biggest decline in physical activity amongst Australian's has been in the 25-34 age group (Australian Institute of Health and Welfare, 2012b). The financial burden of physical inactivity in Australia has been estimated to be \$13.8 billion for the year 2008 (KPMG Report, 2008). It would be assumed that with physical inactivity rates increasing, the financial burden will be much greater in future years.

Globally, the progress in raising awareness of the detrimental effects of alcohol and tobacco and demonstrating the importance of a healthy diet, have made steady progress (Kohl et al., 2012). Unfortunately, the promotion of activity and consequent reduction in inactivity has not received the same amount of attention, perhaps providing a reason for such high levels of inactivity.

Initiatives such as Exercise is Medicine® developed by the American College of Sports Medicine and the American Medical Association have been adopted by many countries and are designed to ensure that exercise is a primary focus on disease prevention, health and wellness (Exercise is Medicine, 2008). This particular initiative is designed to improve the health and wellbeing of individuals through regular physical activity in an attempt to improve both the public's health and the financial burden associated with inactivity (Exercise is Medicine, 2012).

The Pfizer Australia health report from Sports Medicine Australia has found that one of the major reasons individuals do less physical activity currently is that more time is spent sitting (Pfizer Australia, 2007). The increase in sitting has been associated with leisure time sitting, time spent sitting in cars, and watching television. Other reasons for the increase in inactivity includes major technological innovations of automation, labour saving devices in the home and the necessity to be reliant on automobiles due to widely dispersed suburban locations (Transportation Research Board Institute of Medicine: Committee on Physical Activity Health Transportation and Land Use, 2005). This increase in sedentary behaviour is associated with higher mortality risk, especially from cardiovascular disease (Veerman et al., 2012).

The report highlighted that there is a lack of recreational options available for individuals wanting to become active and also that children especially should participate in a variety of activities that are fun and challenging (Pfizer Australia, 2007). It is therefore important to note that the built environment can facilitate or constrain physical activity, although it is complex and operates through many mediating factors including socio-demographic characteristics, personal and cultural variables, safety and security and time allocation (Transportation Research Board Institute of Medicine: Committee on Physical Activity Health Transportation and Land Use, 2005). It has been recommended that those responsible for modification of the built environment should facilitate access to, enhance the attractiveness of, and ensure the safety and security of places where people can be physically active (Transportation Research Board Institute of Medicine: Committee on Physical Activity Health Transportation and Land Use, 2005).

The recent establishment of Waterways Authorities in Australian towns is designed to improve access, manage water based activities and maintain key coastal assets of regional tourism and recreational areas (Queensland Government: Department of Transport and Main Roads). Stand up paddle boarding seems like an ideal activity to fill this need as it is a viable, accessible and is reported to be an enjoyable exercise modality. It is imperative that organisations like the waterways authorities continue to provide access and ensure safety on waterways for SUP to provide a means of physical activity.

6.3.3 The Effects of Activity on Quality of Life

The association between quality of life and physical activity is well established (Rosenkranz et al., 2013). Self-rated quality of life is a concept which is used to summarise the wellbeing of individuals and societies (Australian Institute of Health and Welfare, 2012b). It comprises many aspects including physical health, psychological well-being, levels of independence and functioning, social support networks, material resources and personal beliefs (Australian Institute of Health and Welfare, 2012b).

In 1991, the World Health Organisation (WHO) developed an international, cross-culturally comparable quality of life assessment instrument called the World Health Organisation Quality of Life assessment WHOQOL (Murphy, 2000). It is an individual assessment of the perceptions in the domains of physical and psychological health, social relationships and the environment (World Health Organisation, 1993). The WHO defines quality of life as individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns (World Health Organisation, 1997).

In the 2007 National Survey of Mental Health and Wellbeing in Australia, most respondents who rated their physical health as good, very good or excellent were also satisfied with their quality of life (Australian Institute of Health and Welfare, 2012b). Conversely, those who rated their health lower also were likely to report mixed feeling regarding their quality of life. It is therefore evident that there is also an intimate relationship between health and quality of life.

The impact of improving health and well-being through enjoyable means of physical activity and demonstrating measurable change on quality of life questionnaires has been previously reported

in the literature. Physical activity is reported to have a positive relationship and quality of life, although it is dependent on the type and intensity of the activity (Pucci, Reis, Rech, & Hallal, 2012). Physical activity in leisure time demonstrated a consistent association with quality of life, whereas physical activity for transport did not. Major findings from previous studies are that individuals performing more than 150 minutes per week of moderate physical activity presented with a score 5.3 points higher than their more sedentary counterparts. The significance of this marginal increase is demonstrated by other researchers indicating that a rise of 10 points on the WHOQoL may increase survival rates by 9% (Braun, Gupta, & Staren, 2011).

Summary

It can therefore be seen that SUP may be ideally placed to promote as an easy to learn fitness alternative to address the societal problem of inactivity and the physical and psychological issues associated with it. Results from this thesis show that it can have positive effects on a wide range of physiological and musculoskeletal attributes in addition to positive psychological benefits. It appears as though the self-rated psychological benefits are primarily physical and psychological health based, while self-rated benefits in social and environmental domains may take longer to be maximised. Despite small sample sizes, it appears as though long term follow up of SUP participants shows the benefits achieved over a six week period can continue to improve and be maintained over a full year.

Chapter 7

Discussion, Limitations and Future Research

Previous to this research, a review of the literature demonstrated that there has been minimal scientific investigation in to stand up paddle boarding from a performance perspective or from its use as a training tool for health and fitness benefit (Ruess et al., 2013a, 2013b). Although no comparative data on SUP existed, sports deemed similar to SUP and instability training were utilised for comparison. Due to the paucity of research, a greater understanding of the sport was determined via a field based performance analysis of a competition. Outcome measures which could be utilised for SUP needed to be investigated and subsequently applied to a group of SUP participants. This thesis aimed to uncover important performance attributes important for success in SUP and to determine the effects of SUP on various health and wellbeing parameters for the previously untrained individuals.

The main findings from the initial methodological study in this thesis was that ergometers designed specifically for training in SUP can be utilised in the laboratory to measure maximal aerobic capacity with high correlation to field based measures. Therefore future studies can be confident that measurement of aerobic capacity in the laboratory will be highly correlated to field based measures. The elite SUP athletes tested in this study also have aerobic power similar to other upper limb dominant water based athletes including surfers, dragon boat racers and canoeists. The propensity for the portable gas unit utilised in this investigation, the K4b2 from Cosmed has been found to consistently measure higher than the laboratory based measures (Duffield, 2004). This variation should be noted for future research if field based assessment of maximal aerobic power is performed.

The performance analysis of open ocean races by GPS shows that race tactics play an important part on performance and that there is a high variability in distances covered during the race due to both intrinsic (chosen race line, swell/waves caught) and extrinsic variables (tide, waves &

wind). Although performed outdoors, GPS analysis of SUP events in remote locations proved to be challenging. With more sophisticated 15Hz units which require a greater number of satellites, issues of signal drop out were discovered initially with the Molokai to Oahu Race. It is suggested that future researchers ensure adequate coverage of satellites before attempting any GPS based performance analysis.

The profile of the elite SUP athlete seems to require a high level of aerobic and anaerobic fitness amongst its participants. Elite participants appear to have a lean body composition with low levels of body fat. Trunk muscle endurance and dynamic balance seems to be important to the elite population in this sport. The values representative of elite SUP athletes with respect to fitness, strength and balance are presented here and can aid in athlete preparation, selection and training.

Using SUP as a training tool for the previously untrained individual can have significant positive effects of fitness (both aerobic and anaerobic), trunk muscle endurance and quality of life. Given the magnitude of health problems associated with inactivity, inadequate fitness and strength, SUP could be a viable training tool to promote in an attempt to reverse the trend of health problems. Due to many health promotions being aimed at the dangers of sitting excessively, SUP seems to be an ideally placed option for an exercise modality. Given that time constraints are often the primary reason provided for people's level of inactivity, an exercise which has proven benefits on fitness, strength and quality of life seems an ideal option for those who are time poor and wishing for a broad range of benefits from an enjoyable activity.

7.1 Limitations

The investigation of SUP via EMG proved to be problematic. Methodological issues with signal drop out, the risk of getting equipment wet and signal noise from excessive body movements were found during the pilot study phase of the EMG investigation. There was a high level of variability in which participants chose to paddle the SUP, due to the varying levels of experience. It is suggested that future studies utilising EMG ensure signal distance is adequate for field based measures, that one demographic of paddler is assessed, and that improved ways of determining trunk muscle MVC are investigated.

A lower number of subjects for both the profiling paper and the intervention study could be another limitation. There was however a desire to profile the elite spectrum of this new sport, and therefore a limited number of elite SUP athletes were available in the local area. To increase subject numbers would be detrimental to the elite classification. As with many training studies, compliance and drop out can be an issue. Despite starting with eighteen subjects once the training intervention began, only thirteen finished the training program. Of these thirteen however, attendance to the program was excellent at 90.27%. Considering asking a sedentary group of individuals to begin a training program with a group of strangers, starting early in the morning, three times per week with a commitment of six weeks, the propensity for subjects to be lost during the training program was expected.

7.2 Future Research

With respect to future research from a performance perspective, currently little is known about optimum paddling stroke on a SUP. As the sport and specifically the competitive aspect of SUP continues to grow, future investigations should explore the anatomical regions most at risk of injury. Longitudinal data is yet to be provided on the prevalence, location and frequency of injuries associated with SUP. Due to the variation in paddling technique of SUP seen in the EMG study of this thesis, information regarding the most efficient and biomechanically sound paddling stroke would be ideal for reducing both frequency and severity of these injuries. A motion analysis of the SUP stroke amongst elite athletes could be developed to aid in this area. Knowledge in this area is paramount to prevention of injuries and management of athletes in SUP.

From a positive health and fitness tool perspective, other pathological conditions which could benefit from participation are yet to be investigated. The association between self-rated quality of life and activity has been addressed in this thesis; however a population afflicted by depression and musculoskeletal pain has not. In addition to the documented positive effects of exercise on obesity, cardiovascular disease and high blood pressure, it has been found that people who exercise have lower rates of depression (Strawbridge, Deleger, Roberts, & Kaplan, 2002). A recent systematic review concluded that exercise is an effective treatment against depression (Eriksson & Gard, 2011).

The present day views of health have changed to align with that of the World Health Organisation, which defines health as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (World Health Organisation, 1946). The necessity to highlight the mental aspect is due to disorders such as anxiety and depression being major health issues with their impact steadily increasing (Eriksson & Gard, 2011). Depression as a specific disease, is the second greatest burden in Australia behind heart disease (Australian Institute of Health and Welfare, 2012a, 2012b). In this context, the burden of a disease is the estimate of healthy life lost due to premature death or prolonged illness or disability (Australian Institute of Health and Welfare, 2012a, 2012b).

Chronic musculoskeletal pain is strongly associated with depression and relates to impaired health related quality of life (Orenius et al., 2012). The association between people suffering from chronic pain and consequent mental illness has been established in the literature. Affective disorders such as depression were found to be 2.5 times more common amongst those with back problems than those without (Australian Institute of Health and Welfare, 2012a).

The interrelationship between pain and depression and the negative associations of the two may be influenced by SUP. As SUP is low impact, it could be used as a means to strengthen arthritic joints of the lower limb without exacerbating painful symptoms. It is feasible to consider that it may be of benefit across the ages. Generalised, progressive resistance training and aerobic training are often prescribed for their health benefits for their elderly and can prevent osteoporosis and sarcopenia in the elderly and also have a positive effect on hypertension (Sharman & Stowasser, 2009).

Although it wasn't the purpose of this investigation, one participant from the intervention study reported a drop in blood pressure of 20mmHg. As hypertension is a risk factor for the development of cardiovascular disease, it may be another way to influence the health status of participants. Hypertension is one of the most common medical disorders which can be prevented or depending on severity, managed with lifestyle modification and exercise (Pescatello et al., 2004). Worldwide, elevated blood pressure has been found to be responsible for more death and disease than any other risk factor (Lopez, Mathers, Ezzati, Jamison, & Murray, 2006). Estimates are that approximately 29% of the Australian population have hypertension (Sharman & Stowasser, 2009). Lifestyle change and exercise are often the first choice of treatment as they are cost effective and of minimal risk and interact favourably with other risk factors of CVD (Pescatello et al., 2004).

Concomitant musculoskeletal complaints and vascular occlusive diseases often prevent older people from utilizing such methods as walking, jogging or cycling for fitness (Westhoff et al., 2008), perhaps ideally placing a low impact, easy to learn activity such as SUP. Various populations including those with depression, hypertension, musculoskeletal pain and arthritis could be incorporated into intervention studies in order to definitively assess whether SUP could be used as an alternative treatment modality for such problems is a logical next step for investigation.

7.3 Summary

The intention of this thesis was to investigate SUP as a new sport and recreational activity. This information has provided novel data on the attributes important for success in SUP and also provides insight into the benefits associated with its participation. In summary, stand up paddle boarding seems to be an ideal exercise option for those people who consider themselves to be time poor. Given the documented physiological, musculoskeletal and psychological effects of SUP and its relative ease and accessibility, it appears to be a novel but beneficial exercise tool with a range of positive health and fitness effects.

Concluding Statements and Key Features

Concluding Statement

Stand up paddle boarding is a new sport and recreational activity in which until now, only anecdotal evidence has existed for its benefits. It appears to be an enjoyable, alternative means of training with a multitude of health and fitness benefits. Stand up paddle boarding is comparatively easy to learn, accessible and able to be used across a variety of ages. This thesis has uncovered novel data in regards to the performance aspects essential for success in SUP from a competitive aspect and also provides some evidence for the positive health and fitness benefits associated with its participation.

Key Features

- 1) Until now there was minimal quality scientific research performed on stand up paddle board. This thesis provides scientific research from a performance perspective and also from a general training/rehabilitative tool.**
- 2) SUP racing appears to be an aerobic endurance event in which maintenance of heart rate at near maximal levels is required for the duration of the event. Tactics, intrinsic and extrinsic variables on the day of the event will affect competition placing's, not simply the shortest distance covered during the race.**
- 3) It appears as though the assessment of physiological and musculoskeletal profiles of SUP athletes can be done utilising methods used in other sports both in the laboratory and field.**
- 4) Elite SUP athletes show high levels of aerobic and anaerobic fitness, comparable to other elite water based athletes. A superior level of fitness, strength and balance exists in those classified as elite when compared to recreational participants, believed to be due to more exposure to the activity.**
- 5) Significant improvements in physiological, musculoskeletal and psychological attributes can be elicited in a six week period. SUP seems to be an ideal alternative exercise modality with a plethora of benefits which could be used to combat a wide range of pathological conditions.**

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Appendix:



Ethics Approval

10 October 2012

Ben Schram
Faculty of Health Sciences &
Medicine
Bond University

HUMAN RESEARCH
ETHICS COMMITTEE
Bond University
Gold Coast, Queensland 4229
Australia
Ph +61 7 5595 4194
Fax, +61 7 5595 1120
(from overseas)
Email buhrec@bond.edu.au

Dear Ben

Protocol No: RO 1550

Project Title: Stand Up Paddle Boarding: An analysis of a new sport

I am pleased to confirm that your project was reviewed under the Full review procedure of Bond University's Human Research Ethics Committee and you have been granted approval to proceed.

As a reminder, BUHREC's role is to monitor research projects until completion. The Committee requires, as a condition of approval, that all investigations be carried out in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Research Involving Humans and Supplementary Notes. Specifically, approval is dependent upon your compliance, as the researcher, with the requirements set out in the National Statement as well as the research protocol and listed in the Declaration which you have signed.

Please be aware that the approval is given subject to the protocol of the study being undertaken as described in your application with amendments, where appropriate. As you may be aware the Ethics Committee is required to annually report on the progress of research it has approved. We would greatly appreciate if you could advise us when you have completed data collection and when the study is completed.

Should you have any queries or experience any problems, please contact early in your research project: Telephone: (07) 559 53554, Facsimile: (07) 559 51120, Email: buhrec@bond.edu.au.

We wish you well with your research project.

Yours sincerely

Dr Mark Bahr Chair

Explanatory Statement



Date: 12 SEP 12

Project title: Stand Up Paddle Boarding: An analysis of a new sport

Ethics Reference Number: RO-1550

Stand Up Paddle Boarding: An analysis and potential of a new sport

My name is Ben Schram and I am currently completing a PhD in the Water Based Research Unit at Bond University under the supervision of Professor Wayne Hing and Associate Professor Mike Climstein.

I am conducting a research investigation into the sport of Stand Up Paddle Boarding. I am specifically interested in the aerobic and anaerobic fitness, strength, balance and endurance of elite and recreational Stand Up Paddle Boarders and what health and fitness gains the average person could potentially obtain from participation in this unique sport.

As part of this study, I will invite you to complete a few hours of testing on site at Bond University where various measures of physical capability, including strength, endurance and fitness tests will be conducted. Fitness testing will be performed on a SUPergo which is similar to a rowing machine, balance tests performed on a force plate and endurance tests performed by maintaining positions as long as possible.

We are looking for fit and healthy 18-60 year olds who have been paddle boarding for at least a year. We will accept people who have no history of back pain, no current lower limb injury, are not currently pregnant, have no documented history of mental health disorders, balance disorders or neurological impairment.

Participation in this study is **completely voluntary** and you may withdraw at any time without risking any negative consequences. If you choose to withdraw your participation in this study, the information you have provided will be immediately destroyed. All the data collected in this study will be treated with complete **confidentiality** and not made accessible to any person outside of the 3 researchers working on this project. The information I obtain from you will be dealt with in a manner that ensures you remain **anonymous**. Data will be stored in a secured location at Bond University for a period of 5 years in accordance with the guidelines set out by the Bond University Human Research Ethics Committee.

It is anticipated that the data collected in this study will assist us in understanding the positive physical adaptations which occur from participating in this sport and what the physiological profile of a paddle boarder is. Your participation in this study will help enhance work towards promoting this sport, more effective exercise prescription and injury prevention using paddle boards.

If you experience distress from participation in this research, please contact either of the 3 researchers whose details are listed below.

Should you have any complaints concerning the manner in which this research is being conducted please make contact with –

**Bond University Human Research Ethics Committee,
c/o Bond University Office of Research Services.
Bond University, Gold Coast, 4229**

Tel: +61 7 5595 4194 Fax: +61 7 5595 1120 Email: buhrec@bond.edu.au

We thank you for taking the time to assist us with this research.

Yours sincerely,

Ben Schram

B.Ex.Sci., DPhty.

Faculty of Health Science & Medicine

Bond University

Email: bschram@bond.edu.au

Professor Wayne Hing

PhD, MSc (Hons), ADP (OMT) Dip MT, Dip Phys, FNZCP

Research Supervisor

Faculty of Health Science & Medicine

Bond University

Tel: (07) 5595 3037

Email: whing@bond.edu.au

Associate Professor Mike Climstein

PhD, FASMF, FACSM, FAAESS

Research Supervisor

School of Health Science & Medicine

Bond University

Tel: (07) 5595 4792

Email: mclimste@bond.edu.au

Participant Informed Consent Form



Participant Informed Consent Form

Project title: Stand Up Paddle Boarding: An analysis and potential of a new sport.

BUHREC Protocol Number: RO-1550

Explanatory Statement:

My name is Ben Schram and I am currently completing a PhD in the Water Based Research Unit at Bond University under the supervision of Professor Wayne Hing and Assistant Professor Mike Climstein.

I am conducting a research investigation into the sport of Stand Up Paddle Boarding. I am specifically interested in the aerobic and anaerobic fitness, strength, balance and endurance of elite and recreational Stand Up Paddle Boarders and what health and fitness gains the average person could potentially obtain from participation in this unique sport.

As part of this study, I will invite you to complete a few hours of testing on site at Bond University where various measures of physical capability including strength, endurance and fitness tests will be conducted. Fitness testing will be performed on a SUPergo which is similar to a rowing machine, balance tests performed on a force plate and endurance tests performed by maintaining specific positions as long as possible.

As the physical tests are maximal tests, some soreness may be felt post testing. You will be given the opportunity for an adequate warm up and cool down. These tests are a routine part of athletic testing however.

Participant Informed Consent

I agree to take part in the above Bond University research project. I have read the Explanatory Statement. I am willing to:

- Conduct a test of aerobic/anaerobic capacity
- Perform tests of endurance by maintaining positions as long as I am able to.
- Perform a postural sway assessment on a force plate from where the amount of sway will be recorded to a computer.
- Have musculature measure by EMG.
- Have GPS and heart rate monitors attached to me during a race.

I understand that my identity will be kept from being made public by anonymously labelling data and keeping all data in a secure location at all times.

I understand that my participation is voluntary, that I can choose not to participate in part or all of the project, and that I can withdraw freely at any stage of the project.

Should you have any complaints concerning the manner in which this research is being conducted please make contact with –

**Bond University Human Research Ethics Committee,
c/o Bond University Office of Research Services.**

Bond University, Gold Coast, 4229

Tel: +61 7 5595 4194 Fax: +61 7 5595 1120 Email: buhrec@bond.edu.au

Please tick the appropriate box

- ☐ The information I provide can be used by other researchers as long as my name and contact information is removed before it is given to them.
- ☐ The information I provide cannot be used by other researchers without asking me first
- ☐ The information I provide cannot be used except for this project

Name:.....

Signature:..... Date:.....

Witness Name:.....

Signature:..... Date:.....

WHO-QoL BREF Questionnaire

WHOQOL-BREF

UK VERSION



Department of Mental Health

World Health Organisation

Geneva

For Office Use Only

	Equations for computing domain scores	Raw score	Transformed score	
			4-20	0-100
Domain 1	$(6-Q3) + (6-Q4) + Q10 + Q15 + Q16 + Q17 + Q18$ $\square + \square + \square + \square + \square + \square + \square$	=		
Domain 2	$Q5 + Q6 + Q7 + Q11 + Q19 + (6-Q26)$ $\square + \square + \square + \square + \square + \square$	=		
Domain 3	$Q20 + Q21 + Q22$ $\square + \square + \square$	=		
Domain 4	$Q8 + Q9 + Q12 + Q13 + Q14 + Q23 + Q24 + Q25$ $\square + \square + \square + \square + \square + \square + \square + \square$	=		

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ABOUT YOU

Before you begin we would like you to answer a few general questions about yourself: by **circling** the correct answer or by **filling in the space provided**.

What is your gender? **MALE** / **FEMALE**

What is your date of birth? ____/____/____. (day/month/year.)

What is the highest education you've received? **None at all**
Primary school
Secondary school
Tertiary

What is your marital status? **Single** **Separated**
Married **Divorced**
Living as married **Widowed**

Are you currently ill? **YES** / **NO**

If something is wrong with your health what do you think it is?

Please write your illness(s) or problem here: _____

Instructions

This questionnaire asks how you feel about your quality of life, health and other areas of your life. **Please answer all the questions**. If you are unsure about which response to give to a question, **please choose the ONE** that appears most appropriate. This can often be your first response.

Please keep in mind your standards, hopes, pleasures and concerns. We ask that you think about your life **in the last two weeks**. For example, thinking about the last two weeks, a question might ask:

		Not at all	Not much	Moderately	A great deal	Completely
	Do you get the kind of support from others that you need?	1	2	3	4	5

You should **circle** the number that best fits how much support you got from others **over the last two weeks**. So you would circle the number 4 if you got a great deal of support from others as follows:

		Not at all	Not much	Moderately	A great deal	Completely
	Do you get the kind of support from others that you need?	1	2	3	4	5

You would circle the number 1 if you did not get any of the support that you needed from others in the last two weeks. Please read each question, assess your feelings, and **circle** the number on the scale for each question that gives the best answer for you.

2

		Very poor	Poor	Neither poor nor good	Good	Very good
1	How would you rate your quality of life?	1	2	3	4	5

		Very Dissatisfied	Dissatisfied	Neither Satisfied nor Dissatisfied	Satisfied	Very Satisfied
2	How satisfied are you with your health?	1	2	3	4	5

The following questions ask about **how much** you have experienced certain things **in the last two weeks**.

		Not at all	A little	A moderate amount	Very much	An extreme amount
3	How much do you feel that pain prevents you from doing what you need to do?	1	2	3	4	5
4	How much do you need medical treatment to function in your daily life?	1	2	3	4	5
5	How much do you enjoy life?	1	2	3	4	5

		Not at all	A little	A moderate amount	Very much	Extremely
6	To what extent do you feel life to be meaningful?	1	2	3	4	5
7	How well are you able to concentrate?	1	2	3	4	5
8	How safe do you feel in your daily life?	1	2	3	4	5
9	How healthy is your physical environment?	1	2	3	4	5

The following questions ask about **how completely** you experience or were able to do certain things **in the last two weeks**.

		Not at all	A little	Moderately	Mostly	Completely
10	Do you have enough energy for everyday life?	1	2	3	4	5
11	Are you able to accept your bodily appearance?	1	2	3	4	5
12	To what extent do you have enough money to meet your needs?	1	2	3	4	5
13	How available to you is the information that you need in your day-to-day life?	1	2	3	4	5
14	To what extent do you have the opportunity for leisure activities?	1	2	3	4	5

The following questions ask you to say **how good** or **satisfied** you have felt about various aspects of your life **over the last two weeks**.

		Very poor	Poor	Neither poor nor good	Good	Very good
15	How well are you able to get around?	1	2	3	4	5

		Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
16	How satisfied are you with your sleep?	1	2	3	4	5
17	How satisfied are you with your ability to perform daily living activities?	1	2	3	4	5
18	How satisfied are you with your capacity for work?	1	2	3	4	5
19	How satisfied are you with yourself?	1	2	3	4	5
20	How satisfied are you with your personal relationships?	1	2	3	4	5
21	How satisfied are you with your sex life?	1	2	3	4	5
22	How satisfied are you with the support you get from your friends?	1	2	3	4	5
23	How satisfied are you with the conditions of your living place?	1	2	3	4	5
24	How satisfied are you with your access to health services?	1	2	3	4	5
25	How satisfied are you with your transport?	1	2	3	4	5

The following question refers to **how often** you have felt or experienced certain things **in the last two weeks**.

		Never	Seldom	Quite often	Very often	Always
26	How often do you have negative feelings, such as blue mood, despair, anxiety, depression?	1	2	3	4	5

Did someone help you to fill out this form? **YES / NO**

THANK-YOU FOR YOUR HELP



The Physiological, Musculoskeletal and Psychological Effects of Stand Up Paddle Boarding

Schram, B.¹, Hing, W.¹, Climstein, M.²

¹Bond Institute of Health and Sport, Physiotherapy, Gold Coast, Australia, ²Bond University Water Based Research Unit, Gold Coast Australia.



Introduction

Physiotherapists routinely utilise exercise as a key component of patient rehabilitation. Stand up paddle boarding (SUP) is a rapidly growing sport and recreational activity where anecdotal evidence exists for its proposed health, fitness and injury rehabilitation benefits. While limited scientific evidence exists to substantiate these claims, our current research has shown that a high level of fitness, strength and balance exists amongst participants of this activity.

Purpose

The purpose of this study was to conduct a 6 week training intervention on a group of previously untrained individuals to ascertain the physiological, musculoskeletal and psychological training effects of SUP.

Participants

A total of 18 sedentary individuals (10 males, 8 females) were recruited for the study. A total of 13 individuals (4 females, 9 males) completed the training program. Participants were without a history of back pain and were free from any physical and psychological impairment. The study was approved by the University Human Research Ethics Committee and each participant formally consented to taking part in the study.



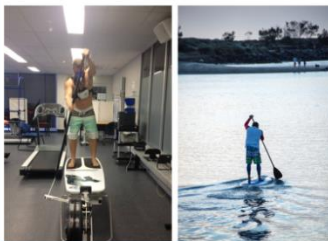
Methods

Participants acted as their own controls with a 6 week control period between first measurements and follow-up measurements prior to the training intervention. A total of 13 SUP participants completed the training study (9 males, 4 females) which was comprised of 3, one hour sessions per week for 6 weeks.

Physiological testing was performed on a specialised SUP Ergometer (KayakPro, Miami, FL, USA) and included a graded maximal exercise test to assess aerobic capacity and a 10 second anaerobic test.

Trunk muscle endurance assessments were performed as per McGill (McGill, Beattie, Crosby, & Russell, 2010). The endurance of the flexors of the spine was assessed with the use of the prone bridge, the lateral flexors with the side bridge and the extensors of the spine with the Biering Sorensen test of isometric endurance. The tests were terminated when the participant could no longer hold the horizontal position as determined by the tester and the time was recorded.

Finally a self-rated quality of life questionnaire (WHO-QoL-Bref UK edition) was completed by the participants pre and post training program. It comprises of 26 items across 4 domains of physical health psychological health, social relationships and environment. It was administered pre and post intervention to assess the effect of a SUP intervention on self-rated quality of life measures.



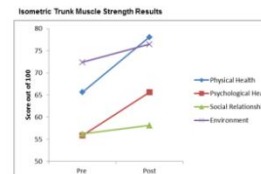
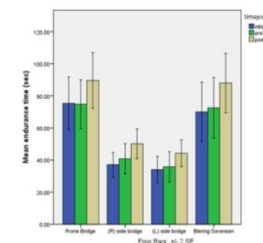
Results

Significant improvements ($p < 0.05$) were identified in aerobic (+23.57%) and anaerobic fitness (+41.98%), multidirectional core strength tests (prone bridge +19.78%, right side bridge +26.19%, left side bridge +28.31%, Biering Sorensen +21.33%) and self-rated satisfaction with participants own health (+28.05%), domains of physical health (+18.99%) and psychological health (17.49%). No significant differences were found in blood profiling, body composition or static and dynamic balance over the duration of the 6 weeks.

Results

Aerobic Performance	Initial Test	Pre-Intervention	Post Intervention
$\dot{V}O_{2max}$ (ml.kg ⁻¹ .min ⁻¹)	20.25 ± 3.92	19.68 ± 3.70	24.32 ± 4.22*
$\dot{V}O_{2max}$ (l.min ⁻¹)	171.46 ± 16.72	172.31 ± 16.10	171.23 ± 15.14
HR _{max} (bpm)	160.52 ± 3.05	115.51 ± 3.24	150.20 ± 3.13*
Average power (W)	2.38 ± 0.46	2.42 ± 0.48	2.52 ± 0.40
Average Stroke Length (m)	41.15 ± 9.10	39.62 ± 5.20	43.77 ± 4.71
Peak stroke rate (strokes/min)	366.68 ± 71.90	336.21 ± 101.97	486.80 ± 134.64*
Distance covered (m)	1.51 ± 0.15	1.56 ± 0.14	1.72 ± 0.12*
Peak speed (m/s)			
Anaerobic Performance			
Absolute power output (W)	14.06 ± 6.08	16.58 ± 7.72	23.54 ± 7.91*
Relative power output (W.kg ⁻¹)	0.16 ± 0.06	0.19 ± 0.07	0.27 ± 0.07*
Peak speed (m/s)	1.60 ± 0.32	1.71 ± 0.32	1.98 ± 0.22*
Distance covered (m)	14.90 ± 2.96	15.28 ± 2.68	17.17 ± 2.48*

Physiological Results (mean ± SD). *significant difference $p < 0.05$



Self Rated Quality of Life results before and after the Training Intervention

Discussion & Conclusions

This was the first study to assess the effects of a training intervention of SUP. The aim of this study was to gain an insight into the musculoskeletal, physiological and psychological effects of a 6 week training intervention on previously untrained individuals.

The multitude of benefits from participation in SUP should be acknowledged. Currently sedentary behaviours contribute to ischemic heart disease, stroke, type 2 diabetes, kidney disease, arthritis, osteoporosis, colorectal cancer and depression (AIHW, 2014) and a common barrier to exercise is a perceived lack of time and a dislike of exercise (Kessler, et al., 2012). The fact that many physiological, musculoskeletal and psychological benefits can be obtained from participation places SUP as an ideal option for those who are time limited and still looking to improve strength and fitness. Due to it being accessible, relatively easy to learn and low impact on the joints is also of great benefit. The obvious psychological benefits and enjoyment obtained from this activity delivers an alternate means of aerobic, anaerobic and strength training than the traditional methods.

These results demonstrate the benefits of participation in SUP for the sedentary individual over a 6 week period. The results also provide evidence to substantiate the claims of health benefits and utilisation of SUP as a potential training and rehabilitation tool.

Implications

Stand Up Paddle Boarding is a fun, low impact, easy to learn and accessible activity/sport that offers numerous physical, musculoskeletal and psychological benefits.

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